The Welding Journal

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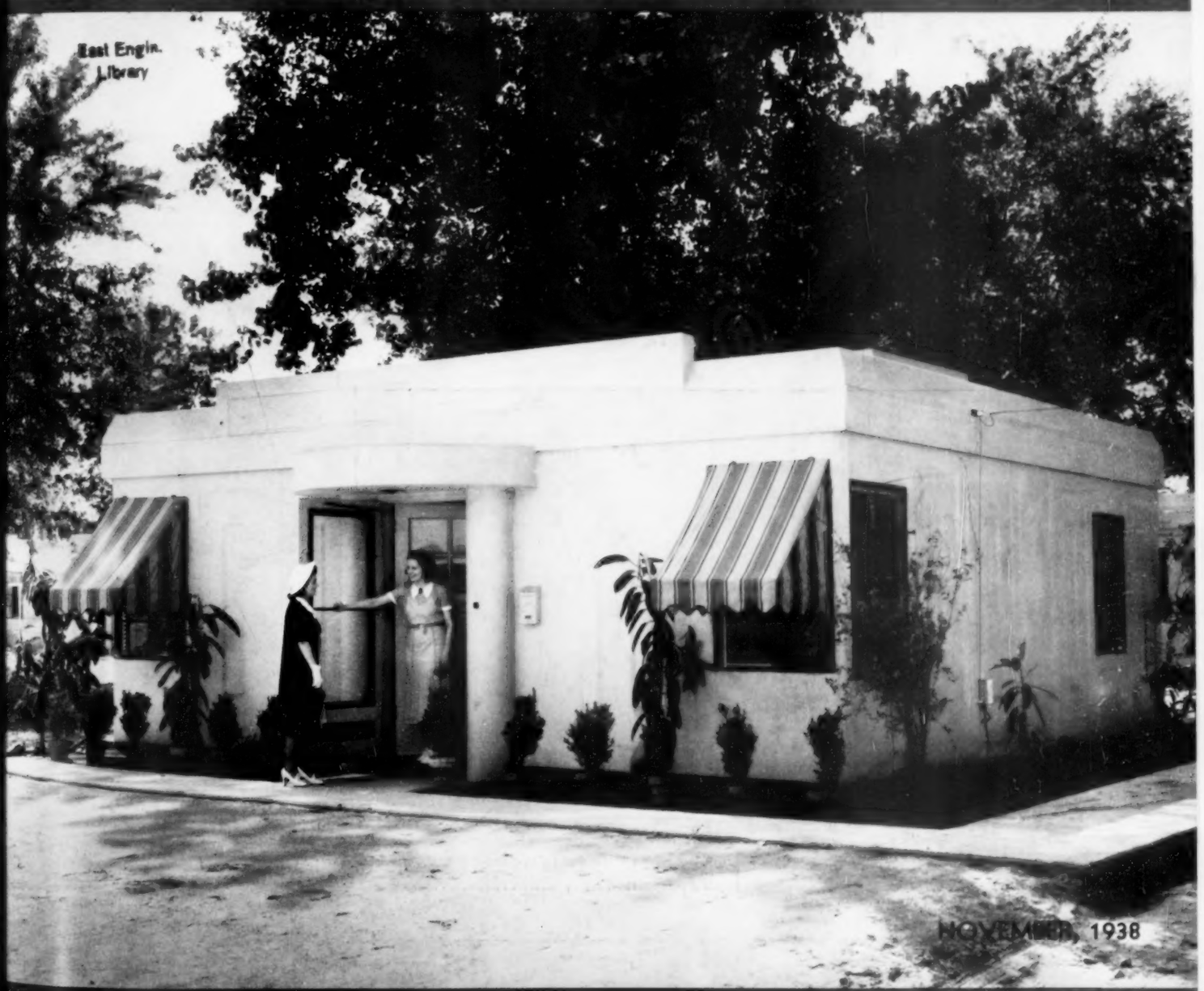

NOVEMBER, 1938

Journal of the American Welding Society

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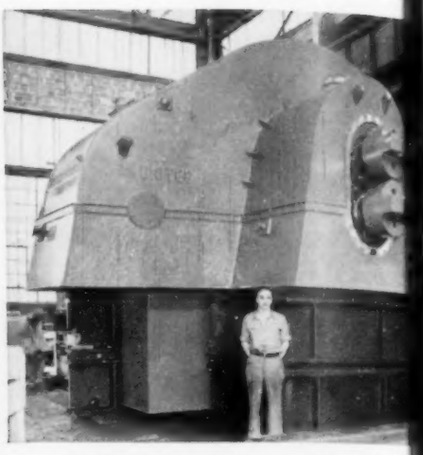
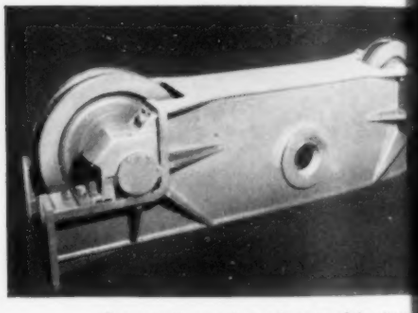
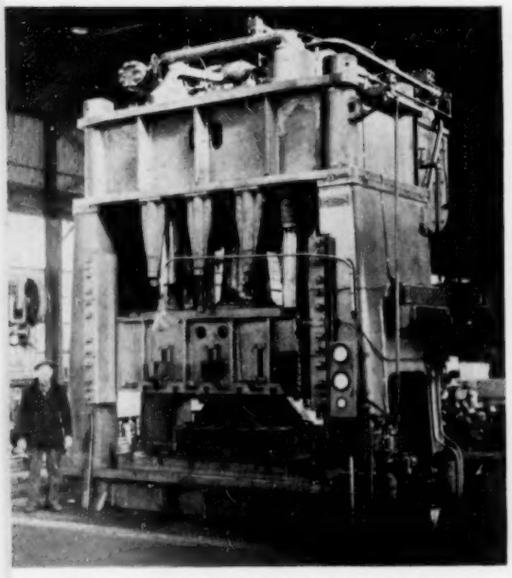
1 Operators like the way Murex handles. The smooth, spatter-free deposits save cleaning time. Higher heats speed work. *Photo courtesy Hamler Boiler & Tank Co., Chicago, Ill.*



2 Where steel mill drives and similar equipment withstand severe shock and vibration, Murex can be depended on. The Murex line includes trodes giving deposits with 100,000 lbs. per tensile strength and better than 20% elongation. courtesy *The Falk Corp., Milwaukee, Wis.*



3 Crane trolley parts are but one of the places welded fabrication is replacing the use of ca with remarkable savings in both weight and Here Murex assures high speed production and good-looking welds. *Photo courtesy Shaw-Box Cr Hoist Co., Muskegon, Mich.*



5 In heavy work, such as the fabrication of the frame for this 800 ton high speed press, many plants report reductions in welding time of more than 20% when using Murex. *Photo courtesy Lukenweld, Inc., Coatesville, Pa.*

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Write, too, for the Murex pamphlet, a handy pocket-size book giving welding characteristics, applications and physical properties for twenty different Murex Electrodes.

4 Ease of handling in tight places, and in and overhead positions speeds installa valves and piping when Murex is used. P properties of welds match alloy steel pipe for sures up to 1500 lbs. per sq. in. and temperatures 1000° Fahr. *Photo courtesy Consolidated Edison pany, New York City.*

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The American Welding Society Journal

W. SPRARAGEN, Editor

Published for the Advancement of the Science and Art of Welding

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An arc welded steel 5-room residence of the type which "sailed" across the Illinois River at Peoria, Illinois. *Courtesy, The Lincoln Electric Company, Cleveland.*

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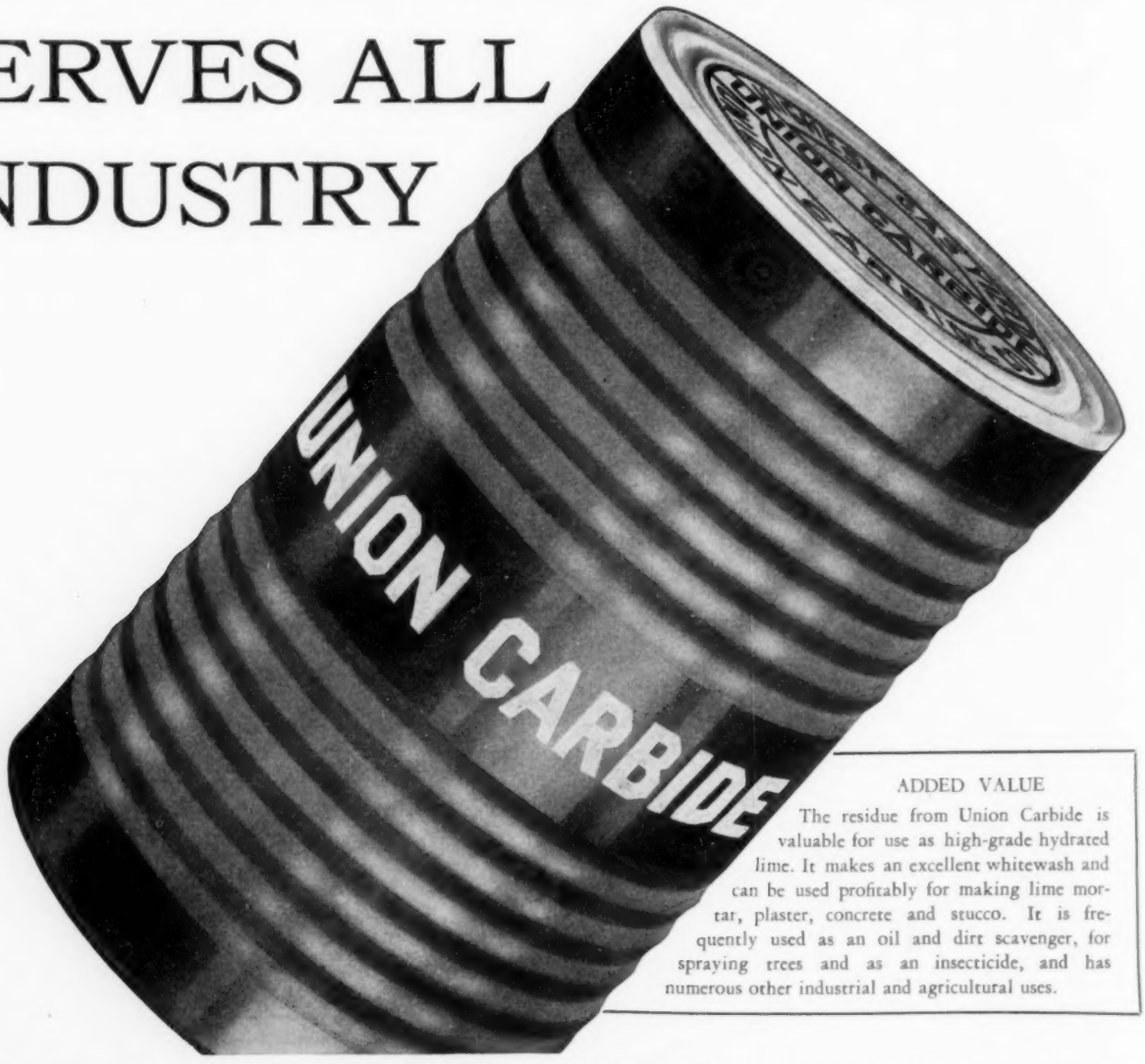

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WELDING HIGH-PRESSURE PIPING

Essex Generating Station*

By H. WEISBERG†

AT THE Essex Generating Station of Public Service Electric and Gas Company, New Jersey, there has recently been completed the installation of a 50,000 kilowatt superposed turbine generator, and two 600,000 pound per hour boilers operating with steam conditions of 1250 pounds, 950° F. at the turbine throttle. It is the purpose of this paper to describe the welding which was done in connection with the piping; and principally, the field welding of the high-pressure, high-temperature steam and water piping for this unit.

As power plant pressures and temperatures have advanced, the maintenance of bolted, riveted and rolled joints in the various parts of the plant has increased to the point where elimination of these joints by welding has become practically a necessity. This is especially true of line joints in piping systems which are subject to stresses caused by expansion as well as pressure and temperature.

Field welding of joints in high-pressure piping was employed for the first time by this company, on a large scale, at the Burlington Generating Station, where a plant operating at 650 pounds, 825° F. was installed in 1932. Up to this time no welded power piping job for as high a pressure and temperature had been attempted, but it was believed that there was sufficient knowledge of the problems involved to make possible a safe and satisfactory installation. Six and a half years of operating experience has proved that this decision was justified, as there have been no failures or troubles with welded joints at this plant.

At Burlington welding was limited to pipe-to-pipe line joints, whereas at Essex practically all line joints were welded. There are only two flanged line joints in the entire high-pressure steam system, and these are in the pipes from the turbine control valves to the upper half of the turbine casing, allowing for the turbine to be opened without cutting the pipe. There are also flanges on the suction and discharge side of the boiler feed pumps to facilitate removal of the pumps for repairs. All other high-pressure apparatus is welded in, including boiler non-return valves, turbine emergency stop valves and control valves, steam reducing valves, feedwater heaters and boiler feedwater regulating valves.

Also, a large percentage of the low-pressure piping is welded. With equipment available for the high-pressure welds, and an organization trained in this method of erection, welding the joints in the low-pressure piping was found to be more feasible from the construction standpoint. In the end it was probably less expensive than using flanged joints. The salt water lines are cement-lined steel pipe joined by butt welds, excepting at valves which are cast-iron flanged. Joints in steel tubing for gage lines down to $^5/_8$ inch O.D. are made with gas welding instead of the usual compression fittings.

In order to demonstrate the advancement within the last few years of the welding art as applied to piping erection, it will be of interest to review the procedure and equipment used on the Burlington and subsequent installations for this company prior to the Essex Unit.

At Burlington, the oxyacetylene process was used as at that time the coated electrode for position arc welding was in the developmental stage and tests indicated that the gas weld gave more satisfactory results than the electric with bare electrode. It was specified that the welds once started should be carried through to completion. On the larger size pipes this required as much as twenty-two hours of continuous welding for two men working simultaneously, which was a tax on the endurance of the men and, therefore, the tendency was to become less careful toward the end. Stress relieving was specified and performed by placing a muffle furnace around the pipe. The furnace was constructed of steel plate lined with asbestos and was fired with two fuel oil burners. A cherry red heat was applied for two hours; the burners removed; the furnace packed full of asbestos and left to cool (Fig. 1).

A minimum tensile strength of 45,000 pounds per square inch and a minimum free-bend ductility of 12 per cent was specified after tests indicated that these results were the best that could be expected. No backing rings were used, and although not as essential for gas welding as for electric, complete penetration to the root of the weld was by no means assured. In view of these considerations reinforcing straps were welded across the joint on all high-pressure piping (Figs. 2 and 3).

The same process was specified for the Kearny installations made in 1932 and 1933.

Later, as the process improved, the reinforcing straps were omitted from the high-pressure feedwater piping only, but heavier wall pipe than would have been neces-

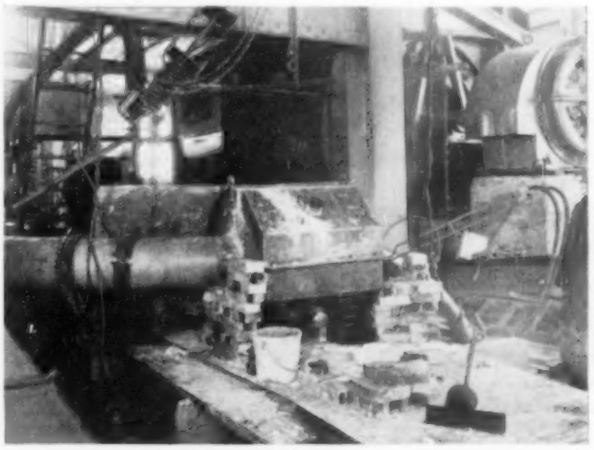


Fig. 1—Burlington Station Annealing Furnace Joints in High-Pressure Steam Piping—1932

* Paper presented before Joint Meeting of Metropolitan Section, A. S. M. E. and New York Section, A. W. S., held September 27, 1938.

† Assistant Mechanical Engineer, Public Service Electric and Gas Co.

Fig. 2—Oxyacetylene Welding High-Pressure Steam Piping
1932

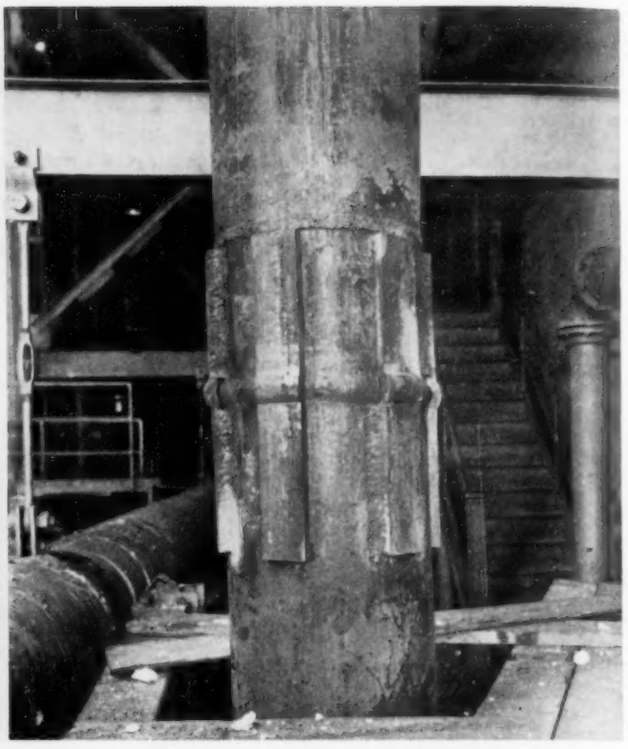


Fig. 3—Welding Reinforcing Straps on High-Pressure Steam Joints
1932

sary for the pressure was substituted as an equivalent safeguard.

Also, at this time experiments were conducted on welding of valves into the lines. Valve manufacturers were reluctant to attempt this but one company was finally persuaded to furnish several valves with special end connections screwed in and welded to the valve body in the shop. As an extra precaution, a cooling ring was provided on each end through which air or water could be circulated to keep the valve cool particularly during the stress-relieving operation (Fig. 4).

Experience proved that the cooling ring was unnecessary as the valve never reached a temperature over 200 to 300° F. during the welding or stress-relieving process. Shortly, thereafter, the manufacturers began to offer valves with welding ends, which now are more or less commonplace

During the installation of the Mercury Boiler Unit at Kearny, a coated rod for position work was perfected which produced welds equal in tensile strength and ductility to the base material, which was carbon steel pipe, and at this time the transition was made from gas to direct current electric welding. The rod and methods for using it were gradually improved until it was possible to obtain welds of ductility far in excess of that of the parent metal.

Next came the development of electric heaters for stress relieving in place of the clumsy oil fired arrangement. The electric furnaces were similar to the muffle oil fired furnaces but were fitted with nichrome resistance heating elements inside the casing. They were smaller and easier to handle than the oil fired furnaces and it was possible to control the pipe temperature much more accurately. Trouble was experienced, however, with the nichrome wire breaking or burning out, often at a time when it was necessary to maintain a heat. Where preheating was desirable these electric heaters were almost as impractical as the original oil fired furnaces, because it was necessary to remove them for welding.

We come now to the Essex installation, which was started in 1937. Steam conditions, specified, involved the use of steel pipe alloyed with approximately 0.5 per cent molybdenum. In order to secure welds of the same composition as the pipe, it was necessary to use an electrode which would deposit such metal. The rod selected consists of a steel welding wire on which asbestos yarn is wound in an open spiral and over which a mineral coating is extruded under high pressure. Molybdenum in the proper proportion is contained in the coating so that a weld of the same composition as the base material of the pipe results.

At this time there was offered on the market, an improved rod for carbon steel pipe. This rod has an extruded cellulose coating of very uniform thickness. Tests indicated that it was easier to manipulate and, therefore, more foolproof than the electrodes previously used. Although the ductility of the weld-metal obtained is somewhat less than was possible with the rods previously used, it is still better than the minimum speci-

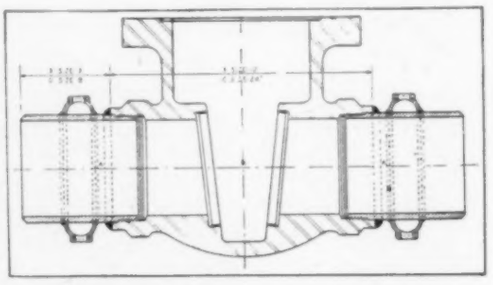
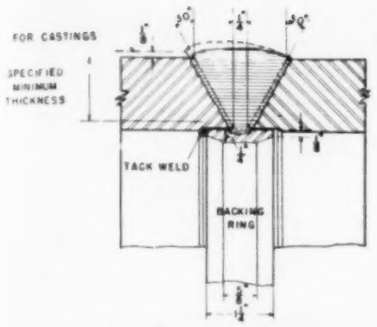
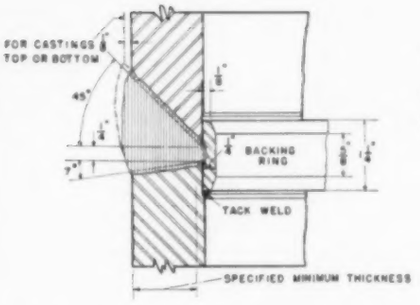


Fig. 4—Experimental Valve with Welding Ends
1932



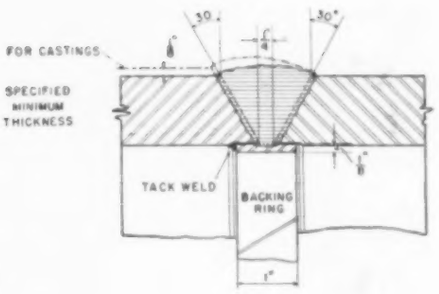
FIELD WELDS FOR CARBON MOLYBDENUM PIPE AXIS LESS THAN 30° FROM HORIZONTAL WALL THICKNESS OVER 1/2

Fig. 5



FIELD WELDS FOR CARBON MOLYBDENUM PIPE AXIS MORE THAN 30° FROM HORIZONTAL WALL THICKNESS OVER 1/2

Fig. 6



FIELD WELDS FOR CARBON STEEL PIPE WALL THICKNESS OVER 1/2

Fig. 7

fied under paragraph U-68 of the Code for Unfired Pressure Vessels. This rod was adopted for the welding of the carbon steel pipe.

Having selected the rods, the next step was to develop the joint detail. Particular attention was paid to the characteristics of the rods which had been selected and to conditions which would be encountered in field welding.

In order to assure full penetration of the weld, a backing ring was used and the pipe ends were spaced 1/4 inch apart at the weld root (Fig. 5). Since the rod chosen had a tendency to burn through thin metal, the backing ring for carbon-molybdenum joints was made 1/4 inch thick. The edges, however, were tapered to 1/8 inch to reduce resistance to flow of the steam. In order to avoid the difficult field job of making the backing rings fit snugly to the inside of the pipe as received from the mill, the inside surface of the pipe adjacent to the end was trued up, concentric with the outside. The backing rings were continuous and made of the same kind of material as the pipe. Everything possible was done to assure a sound start for the weld. Weld details used by others at this time had a "U" shaped cross section which was a machine shop job. It was decided that for field welds it would be desirable to continue the use of the "V" shaped groove with straight sides so as to facilitate field adjustments, and it was found that this could be done without sacrificing quality.

For joints in vertical pipes, the detail was varied somewhat as shown in Fig. 6, providing a flatter surface for the lower fusion zone.

For the carbon steel pipe, the simplest possible joint detail was used and the split backing ring was formed out of 1 inch by 1/8 inch flat iron (Fig. 7). The inside surface of the pipe was machined as for the carbon-molybdenum pipe, as it was found this could be done in the shop at the same time that the pipe end was scarfed. On the thin wall pipe the machining of the inside surface was omitted entirely (Fig. 8).

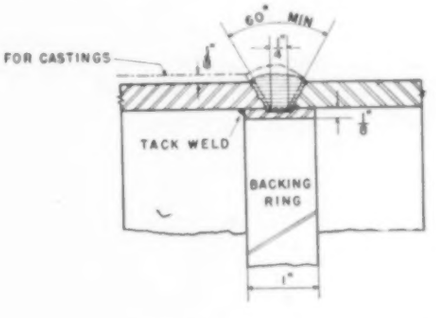
The 60-degree included angle was used for all joint details with the exception of carbon-molybdenum pipe in the vertical position where the included angle was 52 degrees.

For the smaller size high-pressure piping, 2 inches and under, the socket type joint with fillet weld was selected, to avoid the use of backing rings.

A. S. T. M. Specification A-106, Grade A pipe, was specified for carbon steel piping, in order to reduce the possibility of air hardening. Minimum tensile strength of this pipe is 48,000 pounds per square inch, requiring somewhat heavier wall thickness in some cases than Grade B pipe which has a minimum tensile strength of 62,000 pounds per square inch. There were very few cases, however, where it was necessary to go to heavier wall pipe than would be used for Grade B, as wall thicknesses were dictated by considerations other than tensile strength. The carbon content for Grade A was specified not to exceed 0.20 per cent and actually ran 0.09 to 0.18 per cent, whereas Grade B may run as high as 0.30 per cent. The lower carbon content provided an added factor of safety against the possibility of cracking.

Information available from several sources indicated that preheating of the welds was essential for carbon-molybdenum pipe. Also, that cooling of the weld before completion and stress relieving often resulted in cracks. It was specified, therefore, that the pipe at the weld be preheated to a minimum of 400° F. and held at this temperature until the weld was stress relieved.

This requirement made it necessary to reinvestigate the methods for heating and an entirely new arrangement was finally developed and adopted. The heat is generated in the pipe wall by electrical induction rather than in external resistances. While stress relieving by induction heating has been used by others for pipe heating and other uses quite extensively, the method of application to pipe in this case is new, in that the heating element is left in place during the welding process. The pipe on each side of the weld is wrapped with several turns of heavy bare copper cable and a 60-cycle alternating current at 20 to 40 volts is applied across the terminals by means of a transformer connected to the station 220 or 440 volt system. The transformer, together with the required switches and instruments, is mounted on a portable frame. On straight pipe it is sufficient to keep the bare coils at least 1/4 inch apart, insulating them from the pipe by asbestos paper. On valves, fittings, and other irregular shapes, the surface is wrapped with asbestos tape and the coils, which often



FIELD WELDS FOR CARBON STEEL PIPE WALL THICKNESS 1/2 & UNDER

Fig. 8

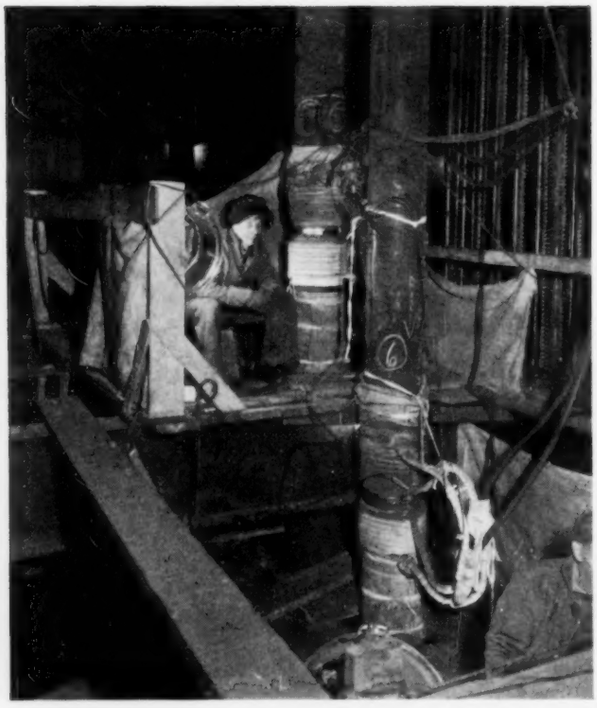


Fig. 9—System for Preheating and Stress-Relieving Pipe Joints

must be crowded together, are encased in an asbestos sleeve. (Figs. 9, 11 to 14).

This method of heating has a number of advantages. The heater remains in place during the entire operation, although heating and welding cannot be carried on at the same time on account of the magnetic effect, which causes the welding rod to vibrate. The arrangement has the advantage over resistance heating in that the cable is heavy and comparatively indestructible, so that there is much less possibility of damage and interruption of the heating cycle. Whereas, with resistance heaters the voltage on the elements is 220 or 440, with the induction method the potential of the heating element never exceeds 40 volts. Pipe temperatures are easily regulated by varying the applied voltage or by turning the current on and off. Temperatures of the weld and adjacent pipe, both on the inside and outside surfaces and along the pipe to the required distance from the weld, are maintained more uniformly than by any other method of heating which was investigated. Where a comparatively thin wall pipe is welded to a heavy wall fitting or valve, the number of turns of cable can be varied on the thin and heavy wall portions so as to result in a uniform heat. The pipe cannot be overheated because between 1350 and 1400° F. the steel becomes non-magnetic so that the transformer begins to draw excessive currents on the primary winding, and will blow the fuses unless it is turned down.

Carbon-molybdenum pipe was stress relieved at 1200 to 1250° F. and carbon steel pipe over $^1/_2$-inch wall thickness at 1150 to 1200° F. These temperatures were held one hour per inch of wall thickness.

Small carbon-molybdenum pipe and valves, 2 inches in size and under, were preheated but not stress relieved. Slow cooling of the weld was required (Fig. 10). The preheating was done by direct resistance heating. A pair of tongs fitted with carbon brush jaws connected to a transformer grasped the pipe and sent a current through it sufficient to bring it up to the specified temperature.

Another requirement specified to insure results was that each layer of weld-metal be chipped down to a fairly smooth surface before applying the next layer. While this involves more work than may be necessary to remove the slag and flux, it made possible the partial inspection of each bead, as applied, and served as a check on the performance of the welder for each layer of metal. The chipped weld also forms a more uniform surface on which to weld and expedites the application of the following bead.

Some interesting tests were run to determine the amount of shrinkage which takes place in the course of making a joint, and it was found that for the heavy wall pipe there is a longitudinal contraction of approximately $^1/_4$ inch in the heated area during the process of completing the weld.

Having worked out the details of the process and equipment to be used, the next step was the qualification of the process and operators. A specification was written assigning limits to all essential variables. The items specified included a list of piping systems to be welded, chemical and physical properties of the piping materials, welding rods to be used, sketches showing joint details, number of welding layers and current characteristics to be used, cleaning of the welds, chipping, preheating, stress relieving, inspection and method of qualification.

The welding process was qualified in accordance with the Tentative Rules for the Qualification of Welding Processes and Testing of Welding Operators, as revised June 1937, published by the AMERICAN WELDING SOCIETY. The Rules do not specify the test results required and it was necessary to determine what these values should be. The A. S. M. E. Boiler Code does specify required test results for piping which is considered a part of the boiler, and since some of the field welds were in that category, it was decided to use those figures for the entire piping system for both carbon-molybdenum and carbon steel.

Briefly these requirements are:

1. 100 per cent of the minimum specified tensile strength of the base material.
2. Free-bend ductility not less than 30 per cent.
3. Complete penetration through the entire thickness of the weld.
4. Absence of oxide or slag inclusions.
5. A limited amount of porosity as specified in detail.

All of the operators who were qualified were men who had had considerable experience with other electrodes and processes. A special training room was set up to give the men an opportunity to become familiar with the new electrodes and materials and to prepare for the qualification tests. Each man was given about one week's training before he made his qualifying welds.

An insurance company inspection service was employed to inspect and check the welding for the duration of the job.

One operator made the qualifying welds for the carbon-molybdenum process. Twelve-inch schedule 160 carbon-molybdenum pipe, the largest size used on the job, was used for the qualifying specimens. Two horizontal-axis and two vertical-axis position welds were made in the presence of the insurance company inspector. After the test specimens had been prepared they were tested in the presence of the same inspector. All of the requirements were met without difficulty. There was no evidence of lack of soundness.

Another operator made the qualifying welds for the carbon-steel process and the same procedure was fol-

Fig. 10—Preheating Small Diameter Pipe, Thermocouple in Position

Fig. 12—Welded Joint in 8-Inch, 1500-Lb. Globe Valve to Pipe. First Pass Completed, Not Chipped

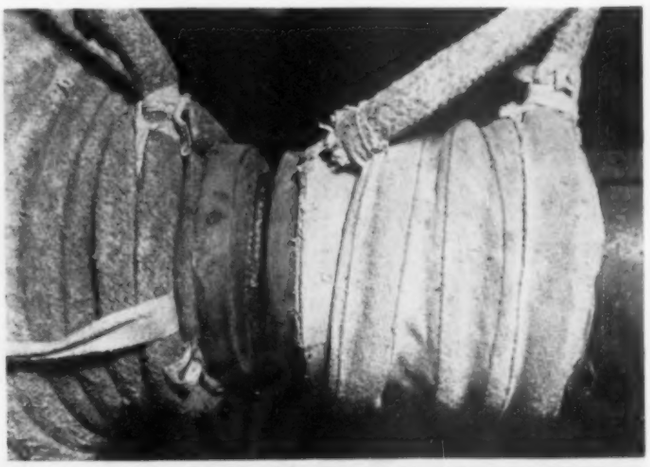


Fig. 11—End of Valve with Backing Ring Tacked in Place in 8-Inch Pipe

Fig. 13—Completed Joint Wrapping Removed

lowed, except that 10-inch schedule 160 carbon-steel pipe was used. The requirements were again met without difficulty. Two small gas pockets were found in one of the horizontal specimens. No slag but a few scattered holes were found in one of the vertical specimens. Otherwise there was no evidence of lack of soundness.

Three additional operators were qualified for the carbon-molybdenum process. As the process had been qualified, they were required only to demonstrate their ability to make sound welds. Each welder made one horizontal-axis and one vertical-axis weld in 12-inch schedule 160 pipe. Test specimens were made for the Side-Break, Nick-Break and Etch Tests. One Nick-Break specimen showed "Small scattered holes but no slag" well within the required minimum, and the other specimens showed no lack of soundness whatsoever.

Seven additional operators were tested for the carbon-steel process in the same manner as for the carbon-molybdenum. The Nick-Break tests of specimens made by four welders revealed porosity within the allowable limit.

The processes and a total of twelve operators were qualified over a period of six weeks.

An expert operator, whose ability was known, was appointed to supervise the operators and inspect their work. He was responsible for the quality of the work and was expected to make sure that it was at least as good as the qualifying welds. The welding procedure was checked by frequent unannounced visits of the insurance company's representatives.

An engineer was designated to operate the preheating and stress-relieving apparatus, and he had an assistant who operated the potentiometer pyrometer and kept the records of the welding, chipping and heating operations.

Each operator was required to stamp his initials on his welds and this practice, together with the inspection of the supervisor and the insurance inspector, was an inducement for careful work and pride of good workmanship.

As far as possible, the day's welding work was planned so that a welding operator and a chipper would work on two joints, the welder working on one while the chipper worked on the other. Every effort was made to provide the best possible working conditions as regards adequate scaffolding and lighting. Because of the provision for keeping the pipe hot during the entire process, it was unnecessary for the operators to work overtime. The 12-inch carbon-molybdenum joints required approximately one week each to complete although the actual welding time varied between twenty and thirty-one hours. The remainder of the time the weld was kept up to a minimum temperature of 400° F.

The approximate total number of welds made in the piping systems was 8700 and the welding work extended over a period of seven months. All the large high-

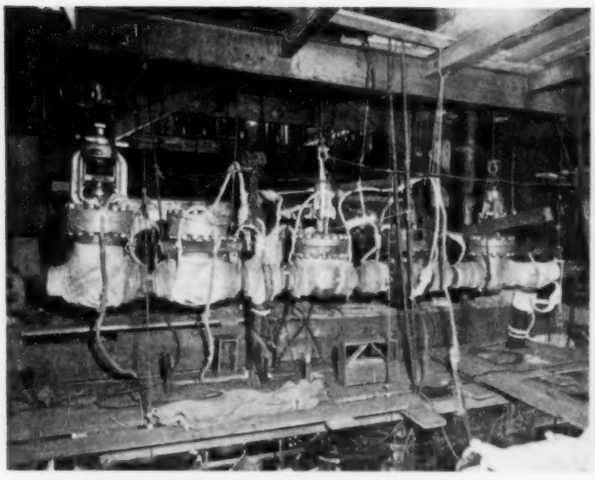


Fig. 14—Valve Assembly Prepared for Preheating and Stress Relieving

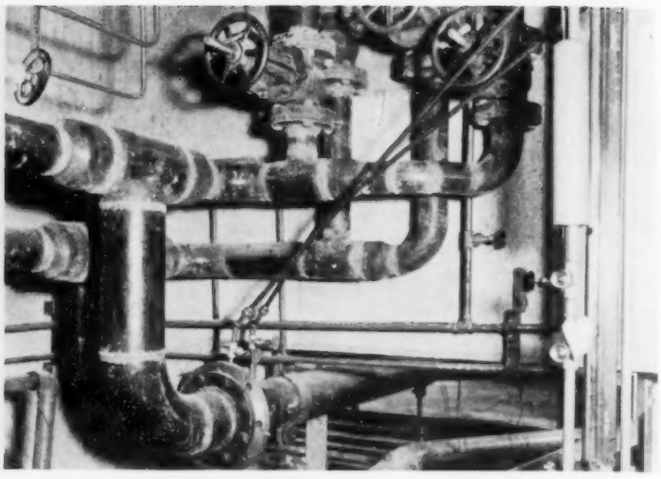


Fig. 15—Welded Cement Lined Piping

pressure steam and feedwater joints were completed in four months.

Careful consideration was given to the possibility of examination of the welds by X-ray, but in view of the satisfactory experience over a period of years with welded piping which was not thus examined, and considering the precautions taken to secure sound joints, it was decided that X-ray inspection of the field welds, in its present state of development, was not warranted for this installation.

Erection of the boilers involved the field welding of 16 joints ranging in size from 8 inches O.D. by $^{7}/_{8}$ inch wall to 20 inches O.D. by $1^{1}/_{2}$ inches wall in the feedwater supply pipe between the economizer and boiler and in the water wall supply downcomers. These joints were made by the same operators using the process described, and the welding was examined by gamma-ray radiograph in order to meet Boiler Code requirements. All welds radiographed were accepted without repairs excepting a small part of one joint which was chipped out to uncover what appeared to be a lack of fusion. It was found, however, to be a very slight undercutting on the inside surface of the pipe at the backing ring due to a small gap between the ring and the inside surface of the pipe. Similar indications on other welds were accepted without further question (Figs. 16 and 17).

No attempt was made to specify the welding process for the shop welds, as the processes and the welders had already been qualified by the insurance company. X-ray inspection of all longitudinal and transverse joints made in the fabrication shop was specified for the more important systems, as this inspection where the pipe can be moved to the X-ray machine is not expensive compared to X-raying at the station. Of course the nozzle welds and other special welds could not be X-rayed.

An interesting feature of the installation is a welded bonnet 12-inch carbon-molybdenum valve for the high-pressure steam piping (Fig. 20). A cleanout hand-hole

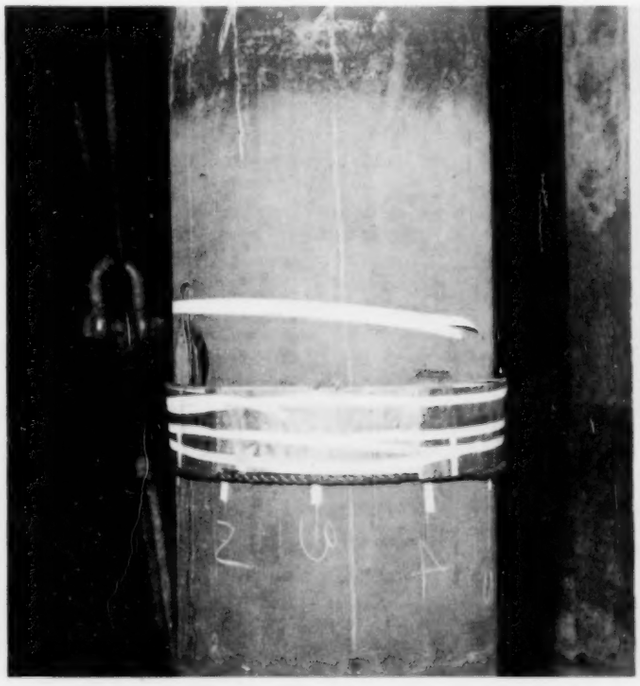


Fig. 16—Gamma-Ray Photo of Weld Being Taken. Vertical Make-Up Pipe

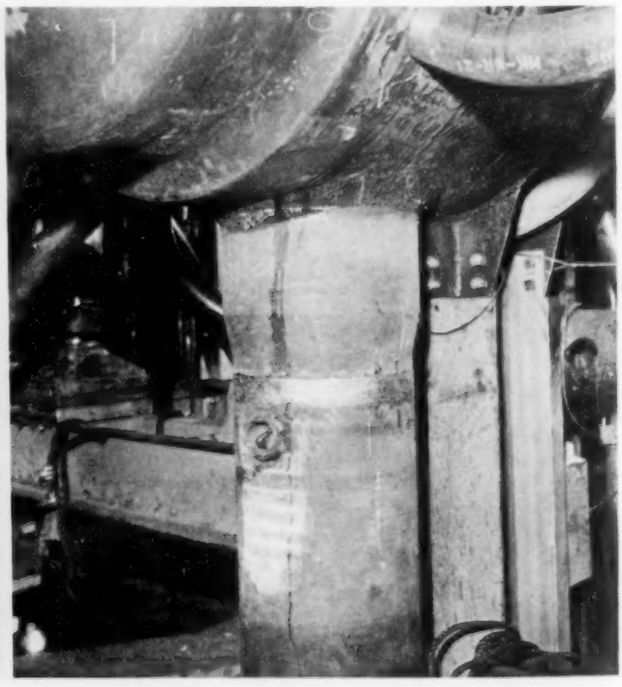
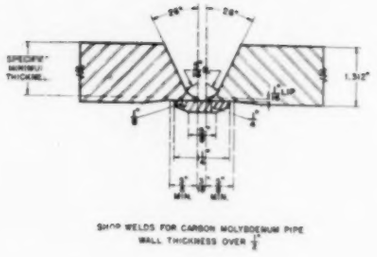


Fig. 17—Plug Tack Welded in Position. Vertical Make-Up Pipe



SHOP WELDS FOR CARBON MOLYBDENUM PIPE
WALL THICKNESS OVER $\frac{1}{2}$"

Fig. 18

is provided in the bottom of the valve for removing foreign material or pipe scale.

Economizer tubes were rolled and seal welded into the headers and also, superheater tubing into the superheater outlet header. In connection with the latter, which contained about 2 per cent chromium and 0.5 per cent molybdenum, it was necessary to preheat the header, and this was done by wrapping for induction heating as described for the pipe heating.

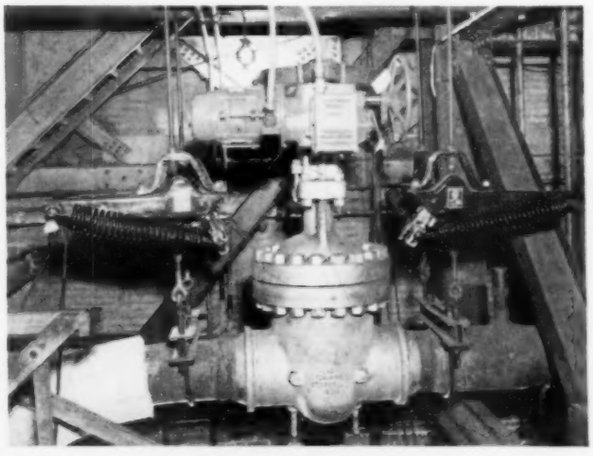


Fig. 19—1500-Lb. Flanged Bonnet Gate Valve

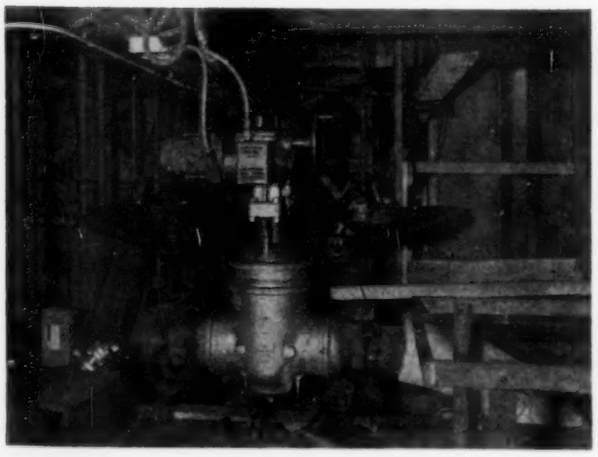
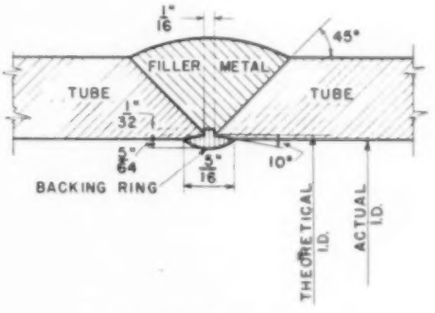


Fig. 20—1500-Lb. Welded Bonnet Gate Valve

Permission was obtained from the insurance company and state authorities for repair of carbon-steel boiler, furnace, superheater and economizer tubing by welding. The latest revision of the Boiler Code now permits such welds. A somewhat different detail of weld is used for this purpose to allow passage of the tube cleaners. Probably both gas and electric welding will be used for these repairs. Gas welding can be done at points which are impossible to reach with the electric weld unless the tube is removed (Fig. 21).

Another use for the induction heating was found in bending pipe that was not fabricated in exact accordance with dimensions and required field adjustment.

The piping was designed and the installation supervised by the Electric Engineering Department, Public Service Electric and Gas Company; erection and welding was carried out by the field forces of the United Engineers & Constructors, Inc., Philadelphia; the piping was fabricated by the M. W. Kellogg Company and



FIELD WELD FOR REPAIR OF BOILER TUBING

Fig. 21

the Midwest Piping and Supply Company; welding machines and stress-relieving transformers were furnished by the Electric Arc Cutting and Welding Co., Newark; welding rod was furnished by the Metal and Thermit Corporation, Jersey City; inspection service by The Hartford Steam Boiler Inspection and Insurance Company; and gamma-ray radiography by The Babcock & Wilcox Company.

The installation has now been in service since the latter part of May of this year. With the exception of two or three minor leaks, in small piping socket welds to large castings, there have been no operating difficulties encountered with welded joints. A 6-inch 225-pound drain pocket on the high-pressure reducing valve failed adjacent to a weld due either to damage in transit or excessive vibration of the reducing valve. A jagged crack 12 inches long developed in the pipe but the leak was detected and the pressure removed before any damage was done. The weld remained intact indicating that it was stronger than the pipe.

It is predicted that as the welding art is further developed, the fundamentals involved are better understood, and the construction and maintenance forces become better equipped for doing this kind of work, further elimination of power plant pressure joints will continue until practically all these joints are made by welding.

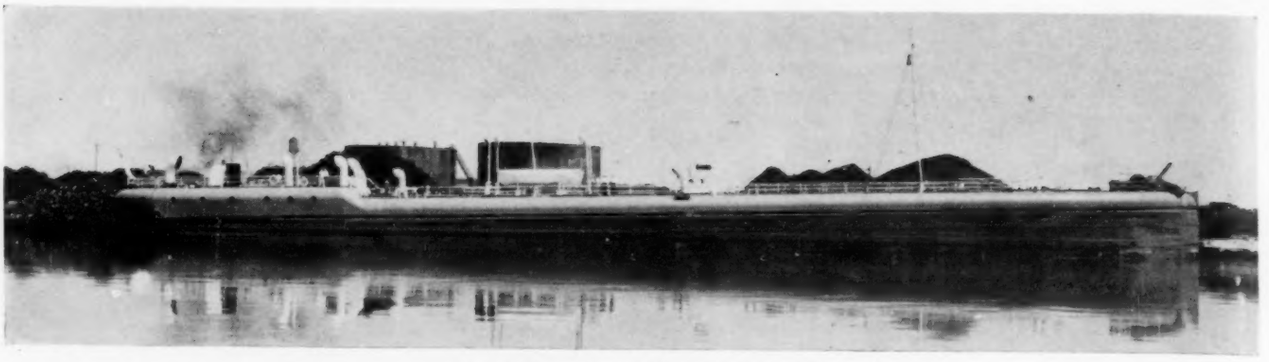


Fig. 1—View of the All-Welded Dolomite IV

NEW ALL-WELDED FREIGHTER HAS PURE Nickel Holds

By E. C. BADEAU*

A NOVEL ship, built in a novel way for a novel service has just completed her maiden trip between Oswego, N. Y. and Chicago.

She is the twin screw Diesel Ship Dolomite IV, 300 feet long and built to full ocean classifications under Lloyd's rating. She has a beam of 43 feet, 4 inches, a molded depth of 20 feet, and a gross tonnage of 5500. Made of electrically welded steel channels bent to form her main structure, she has no rivets. Forty miles of welding were required for her construction.

Built for bulk transportation of lye and other highly corrosive chemicals along the Atlantic seaboard, Dolomite IV has five main bulkhead cargo tanks lined with sheet nickel, which is spot welded to the frame and arc welded on the seams. Although tank trucks and tank cars have been constructed of nickel clad steel and fishing boats are now being built with nickel lined holds to bring fresh fish in from the Atlantic, Dolomite IV is said to be the first freight ship to feature nickel cargo tanks. More than 60,000 pounds of nickel were used for her main tanks.

There is roughly 122 miles of hand-welding on the Dolomite IV and $3\frac{1}{2}$ miles of automatic welding done with the Shielded Automatic Carbon Arc mounted on self-propelled tractor. A current of roughly 900 amperes was used on these Carbon Arc Heads and the speed of welding giving a $\frac{1}{2}$-inch throat on butt welds without scarfing is 35 feet per hour.

The method of constructing the ship was also novel. Her keel was laid in a dry spur of the Erie Barge Canal at Pittsford near Rochester, N. Y. She was "launched" by syphoning water into the lock until she floated, but the traditional champagne was used when she was recently christened by Mrs. Henry Kondolf, of New York City.

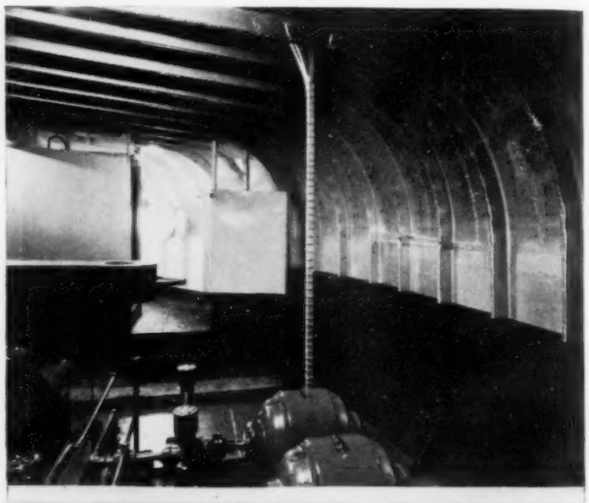
The ship brought a bulk cargo of 1,000,000 gallons of kerosene to Chicago. This is said to be the first time that kerosene has ever been shipped in bulk by water, as it corrodes the metals usually used in cargo tank construction, thus becoming discolored.

On subsequent trips she will carry kerosene one way and grain the other way.

After entering deep sea service in November, she will carry lye between Lake Charles, Louisiana and Norfolk, Va. She will alternate her cargo in this service with molasses, oil, grain and other products.

* Editorial Department, The International Nickel Co., Inc., New York.

Fig. 2—Shows the Under-Deck View and the Method of Welding the Channels Together



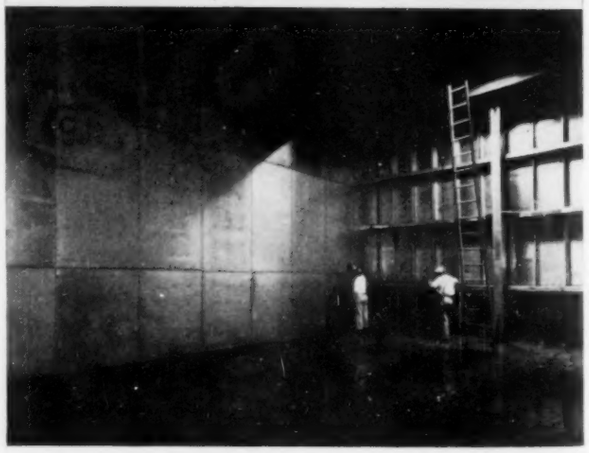


Fig. 3—Shows One of the Tanks with Its Nickel Lining. The Lining Was First Tack Welded and Then Welded Along the Seams. Approximately 58,000 Pounds of Nickel Sheet Were Used to Line the 5 Holds, Each of Which Is 36 Feet Long, 25 Feet Wide and 18 Feet High

Dolomite IV was built and is operated by the Dolomite Marine Corporation of Rochester, N. Y. John H. Odenbach is the president.

FABRICATION and USES of LOW-Alloy High-Strength Steels*

By R. F. JOHNSTON†

THERE has been considerable information and data presented in numerous publications and articles on the properties and characteristics of the recently developed low-alloy high-strength steels so it would seem that a limited discussion of some of the applications of these steels and a few of the problems encountered in their fabrication and welding might be timely.

However, at the risk of repeating familiar knowledge, it may be desirable to describe briefly what is meant by the term low-alloy high-strength steels and wherein they differ from the older high-tensile steels. A number of high-strength steels containing small percentages of various alloying elements have been manufactured for many years. These have been used mostly for structural purposes and to some extent for purposes of limited requirements. They could not be extensively used for the very important reason that they were lacking in one or more important characteristics necessary to make them applicable to many structures. In addition to high elastic ratio and tensile strength, a steel for a wide diversification of application must possess adequate ductility and workability so that it can be fabricated by all the usual methods; superior corrosion resistance in order that sections can be safely reduced without sacrificing durability; high impact strength; greater fatigue or endurance strength; the ability to be welded with the assurance of safe joints; last and possibly most important—cost per unit of strength no greater than plain steel.

These modern steels, due to their chemical and physical characteristics, can be distinguished from the S. A. E. series of steels in that they are used in the "as-received" condition, and are not intended for subsequent heat treatment.

* Presented before Philadelphia Section, AMERICAN WELDING SOCIETY, March 21, 1938.

† Carnegie-Illinois Steel Corp., Subsidiary, United States Steel Corp.

PROPERTIES OF LOW-CARBON STEEL AND OF USS HIGH-TENSILE STEELS UP TO 3/4 INCH

CHEMICAL COMPOSITION	REGULAR OPEN HEARTH (APPROX. FOR SHEETS)	USS COR-TEN	USS MAN-TEN
CARBON, PER CENT	0.05 TO 0.20	0.10 MAX.	0.30 MAX.
MANGANESE, PER CENT	0.30 TO 0.50	0.10 TO 0.50	1.25 TO 1.70
PHOSPHORUS, PER CENT	0.04 MAX.	0.10 TO 0.20	0.04 MAX.
SULPHUR, PER CENT MAX.	0.05	0.05	0.05
SILICON, PER CENT	0.10 MAX.	0.50 TO 1.00	....
COPPER, PER CENT	0.20*	0.30 TO 0.50	0.20 MIN.
CHROMIUM, PER CENT	....	0.50 TO 1.50	....
CORROSION RESISTANCE (ATMOSPHERIC, COMPARATIVE).	1 (OR 2 TO 3 WITH COPPER)	4 TO 6	2 TO 3
YIELD POINT, LB. PER SQ. IN.	25 TO 35,000 MIN.	50,000 MIN.	50,000 MIN.
TENSILE STRENGTH, LB. PER SQ. IN.	35 TO 50,000 MIN.	70,000 MIN.	80,000 MIN.
ELONGATION, PER CENT IN 8 INCHES, 3/16" AND OVER	1,500,000* / T. S.	1,500,000* / T. S.	1,500,000* / T. S.
ELONGATION, PER CENT IN 2 INCHES, UNDER 3/16"	34 TO 25	22	20
COLD BEND		180°d = t	180°d = t
ENDURANCE LIMIT, LB. PER SQ. IN. (NORMALIZED)	25,000	45,000	40,000
MODULUS OF ELASTICITY, LB. PER SQ. IN.	28.-30. x 10^6	28.-30. x 10^6	28.-30. x 10^6

*FOR MATERIAL UNDER 5/16 IN. TO 3/16 IN. INCLUSIVE IN THICKNESS OR DIAMETER, REDUCE ELONGATION 1.25% FOR EACH DECREASE OF 1/32 IN. BELOW 5/16 IN.

Fig. 1

Fig. 2—Modern Light-Weight All Steel Bus

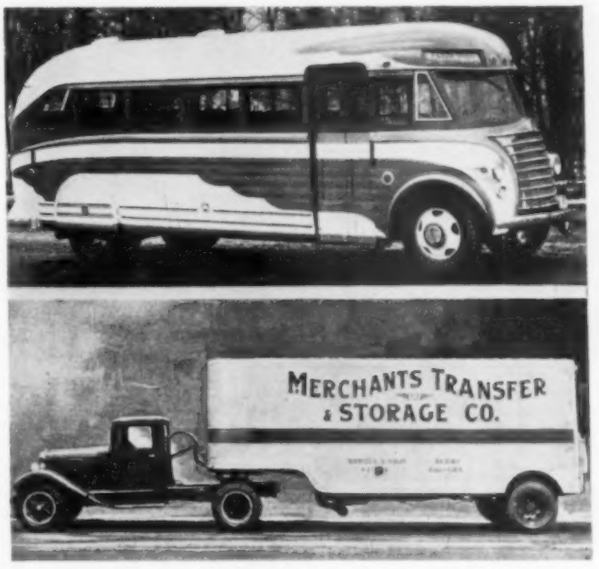


Fig. 3—Large All Welded Semi-Trailer Van

Carbon has been the element commonly used heretofore to obtain hardness and strength in steel. However, the limitations of high-carbon steels such as lowered ductility and impact strengths and decreased weldability are well known. It would appear, therefore, that a high tensile steel for wide application should contain this element in very limited amounts.

Manganese and silicon alone and in combination have been used to some extent. In the plain carbon manganese and silicon steel it may be difficult to obtain the necessary ductility required for fabricating. Also these elements under most conditions do not tend to increase materially the corrosion resistance of steel. The elements—nickel, molybdenum and vanadium—have also been used in considerable quantities.

Chromium is an element that has been found to be very useful in imparting strength and corrosion resistance. The high chromium series of stainless and heat resisting steels are familiar. In the absence of other elements, however, it is necessary to use chromium in a relatively high percentage to give corrosion resistance, thus placing it in the stainless or high cost class. It has been found from extensive research work that as little as 1% chromium in proper combination with copper, phosphorus and silicon affords a superior corrosion resisting steel. Phosphorus in such combination does not add undesirable "cold shortness." Steel of this type has high strength, superior corrosion resistance, adequate ductility, excellent endurance and impact strength and good welding properties. A steel of this combination is manufactured under the trade name "USS Cor-Ten." The

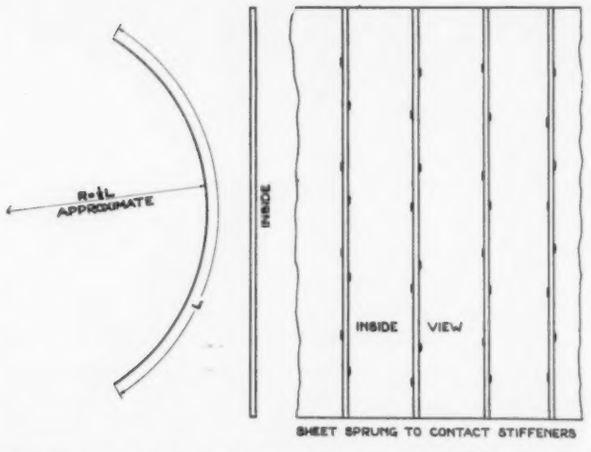


Fig. 4—A Method of Producing Flatness in Sheet by Pre-Rolling Before Welding

superior corrosion resistance of this steel in severe industrial atmosphere, salt spray, fresh and salt water immersion and many other corrosive media has indicated its advantageous use also in many applications where greater physical values alone are not of paramount importance. Table 1 in Fig. 1 indicates the properties of this steel.

In addition to the chromium bearing corrosion resisting high-strength steels there are others of slightly lower cost, such as the medium manganese carbon steel, manufactured under the trade name "USS Man-Ten" which has greater strength than mild steel, but with somewhat lower ductility and weldability and with corrosion resistance on a par with copper bearing steel.

It develops therefore that the decision as to the correct type of steel to be selected for a certain purpose should be predicated on the requirements of the application. These could be analyzed as follows:

1. Extent and severity of fabrication
2. Type and amount of welding
3. Corrosion conditions
4. Impact shocks and
5. Fatigue stresses involved.

While these low-alloy high-tensile steels were developed primarily for the transportation industry, they are finding rapid acceptance in many other applications where lighter weight and/or greater durability are desired.

It is an established economic fact that a reduction in the dead weight of nearly all types of mobile equipment will result in greater pay load capacity, less fuel or power consumption, less dead weight per ton or pound transported and in many cases increased speeds and faster accelerations.

In the following paragraphs, a few of these applications and some of the problems encountered in fabrication are discussed.

STREET CARS, TRACKLESS TROLLEYS AND BUSES

This type of equipment must be as light as possible, not only for economical operation but to meet the present-day schedule demands and faster traffic conditions. At the present writing, nearly 700 of the new light weight street cars have been built or are on order.

These structures have been reduced 15,000 lb. in weight by modern designing and high-tensile steel of the Cor-Ten type. For the most part formed members have been substituted for the rolled sections formerly used, effecting considerable reduction in weight. We also find that welding has played a prominent part in enabling better and more efficient designs to be used. The side sheets have been reduced from the usual 0.100 inch thick to as light as No. 16 gage in some cases. The underframe and framing are assembled by arc welding while the side sheets are spot welded, in order to maintain a smooth exterior. About the only major problem encountered here is maintaining flatness in the side sheets during welding. Stretcher leveled sheets are used and the stagger method of spot welding is employed to keep locked up stresses and distortion at a minimum.

The modern light weight all steel bus, built by the Bender Body Company and shown in Fig. 2 is 1500 lb. lighter due to modern designing and high-tensile steel.

If buckling is encountered in flat panel work of this kind, certain corrective measures may be helpful.

(1) The attachment of stiffeners made of light gage pressed angles to the inside of the panel by spot welding before they are welded to the posts has been helpful. The stiffeners resist the buckling or distortion from the heat and shrinkage of the welds and result in flatter panels.

(2) *Peening of the Spots After Welding.* This method is based on the assumption that each spot is, in actuality, a small casting which shrinks in volume, the cumulative effect of such shrinkage being sufficient to cause excess metal to form a buckle in the panel. The peening of the individual spots with a small airtrip hammer expands them and also stretches the edges of the panel and pulls the excess metal from the center. During the peening, the post or supporting framing member is backed up with a heavy flat piece of steel to avoid bending these members. A little practice will show where the spots should be hammered to give the best results.

(3) *Heating and Shrinking.* This method is not new and is used to a considerable extent in body construction. It consists simply of heating the center of the panel, or where the greatest amount of excess metal occurs, to a cherry heat over an area of several inches in diameter. The surrounding area is then quickly hammered, backing it up at the same time with a heavy flat weight. This hammering causes the metal to upset, resulting in a shrinkage. When it has been shrunk sufficiently, it is quickly chilled with a block of ice to stop the flow of heat to adjacent areas where it is not desired. This operation is repeated if necessary until the panel comes flat.

Figure 3 is a view of a large semi-trailer van, built by the Herman Body Company, St. Louis, with light gage Man-Ten side sheathing, welded to the posts and framing members of Man-Ten. A problem of flatness is sometimes encountered here and a method which is unusual in technique but which appears to give excellent results is illustrated in Fig. 4. This method consists of rolling or barreling the sheets to a radius of approxi-

Fig. 5—Large All-Welded Gasoline Tank Semi-Trailer Construction

mately half the length of that dimension on which the preponderance of welding occurs. After rolling, the sheets are placed against the framing of the body so that the convex surface is against the framing members. They are then pressed into place and welded. This sketch indicates that there are only vertical stiffeners spaced on 14-inch centers and lines of welding develop only in that direction. As stated before, direction of rolling should be governed by the direction or preponderance of welding; in other words, if, as often occurs in car construction, the majority of welds occur along horizontal lines, then the rolling or barreling of the sheets before welding would be done about an axis located 90 degrees from that shown.

Still another method which has indicated promise is the practice of heating the sheets on a large hot steel plate and welding them in the expanded condition. The subsequent shrinkage tends to pull the sheets flat.

Gasoline Truck Tanks. These structures offer considerable advantage for the application of high-tensile steel in that appreciable increased gallonage or capacity can be gained by the use of stronger material and lighter construction.

Figure 5 is a view of one of six large semi-trailers constructed for the Pacific Inland Transport Company by Wentworth and Irwin, Portland, Oregon of Cor-Ten steel. The gain in capacity by the use of high-tensile steel was 800 gallons per unit. The frame was 10 gage, outside heads, bottom sheet and horizontal baffles were No. 12 gage, top sheet and longitudinal baffles were No. 14 gage. Weight of unit loaded 18,025 lb.

While most fabricators are now applying the high-tensile steels to these units with little or no difficulty it might be of interest to review some of the earlier difficulties encountered and the remedies developed. In applying the high-tensile steels the usual procedure is to substitute sheets two gages lighter, although in some cases where the design is such as to indicate the advisability, the bottom or lower one third of the shell has been reduced only one gage in thickness.

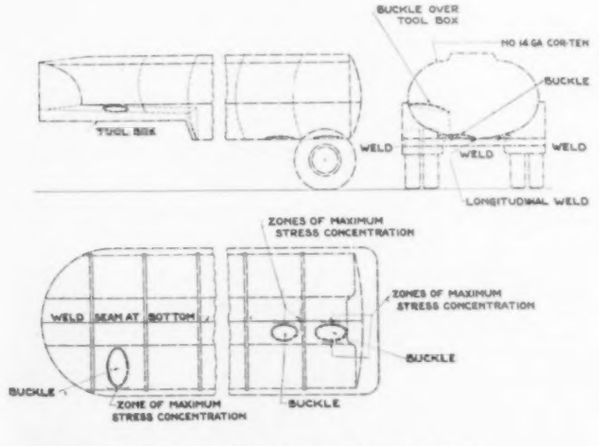
A factor, which was sometimes lost sight of in utilizing the thinner high-tensile steels is the fact that, while the high tensile sheets are approximately twice as strong in tension as the plain blue annealed sheets formerly used, they have the same modulus of elasticity and therefore greater deflection for the same load when the thickness is reduced.

Such deflection usually terminates at some point rigidly fixed such as a supporting member of the tank or where the internal bulkheads are attached. Solutions to this problem might be (1) decreasing the span of the supporting members or (2) the application of additional light weight angle stiffeners. In some cases, the bottom third of the shell has only been decreased one gage in thickness where the conditions indicate, as mentioned before. This also results in placing the longitudinal welds on the sides of the tank near the center or neutral axis where minimum flexing occurs.

Fig. 7—Welded 150 Gallon Cor-ten Tank After Dropping 23 Feet

Another point which might be mentioned is the matter of buckling in welding the thinner sheets. For example, in welding a tank with No. 10 gage heads and No. 12 gage shell of mild steel there may not be sufficient buckling or warping of the sheets to necessitate much flattening or straightening after fabrication. In substituting thinner high-tensile sheets there may be a somewhat greater tendency to buckle or such buckles may be harder to remove due to the greater stiffness of the material. If buckles occur outward on the tank they are of no particular significance, excepting perhaps appearance, but if they should occur inward, they may prove troublesome due to the "oil can" or snapping effect that can result from the pressure created by the surging action of the contents of the tank.

Buckles ordinarily occur, of course, in the sheet adjacent to or near welds where heating occurs. Therefore, if this buckle is of such nature that it can move in and out, the maximum bending may be concentrated at a fixed or rigid welded connection developing a highly concentrated stress area and contributing to a fatigue type of failure. Figure 6 illustrates the above remarks. It is noted that the areas to be considered the most carefully are the bottom of the tank where the radius of curvature is large and the almost flat bottom over the fifth wheel. These sketches illustrate how locations of excessively high stresses can occur due to improper fabrication or design.

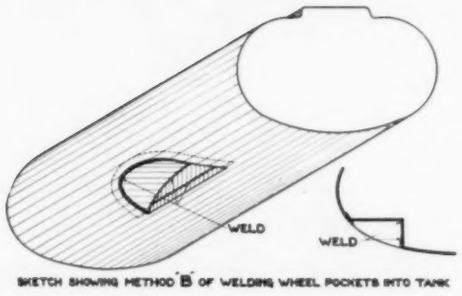


SKETCH SHOWING EFFECT OF BUCKLES CAUSING FAILURE OF TRUCK TANKS

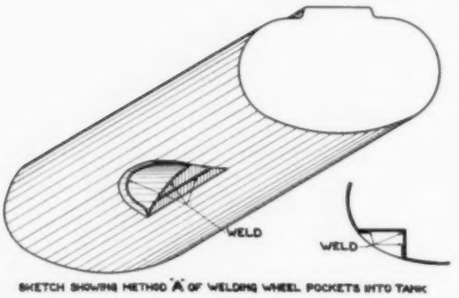
Fig. 6

Reference to Table 1 again, indicates fatigue values for high-tensile steels considerably in excess of the value for plain open-hearth steel. The Cor-Ten steel particularly, it will be noted, has an exceptionally high ratio of fatigue strength to tensile strength, ranging between 0.65 and 0.67. When it is considered that a ratio of 0.50 for plain steels is considered good, this value is indeed remarkable.

A low-alloy high-tensile steel to be suitable for most applications and particularly for gasoline trunk tanks



SKETCH SHOWING METHOD 'B' OF WELDING WHEEL POCKETS INTO TANK



SKETCH SHOWING METHOD 'A' OF WELDING WHEEL POCKETS INTO TANK

Fig. 8

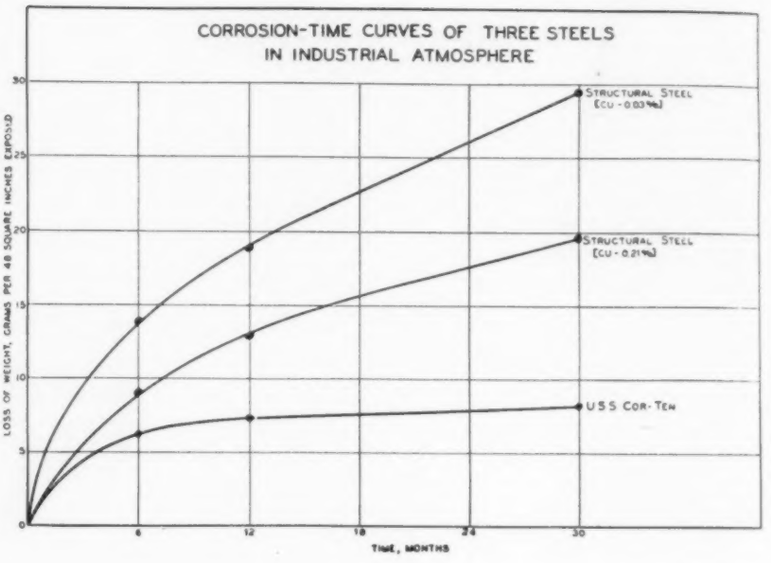


Fig. 9

should be not only strong and ductile, but should have also excellent weldability with as little "air hardening" tendency as possible. It should also have a good impact value.

Figure 7 is a view of one of many drop test tanks that have been made from this steel. The tank illustrated is constructed of No. 14 gage Cor-Ten sheet and has a capacity of 150 gallons. After filling with water it was dropped from a height of 23 feet and even though the welds and base metal were severely distorted, no leaks developed. This indeed exemplifies the ductility that can be attained with welded joints.

Figure 8 illustrates two improved methods of construction of the rear wheel inset. These consist in flanging the parts in such a way that the usual junction of the three weld beads at the lower inside corner is eliminated, thus avoiding the building up of excessive weld-metal and a resultant locus of stress concentration.

FABRICATING

While the fabricating processes for the high-strength steels differ very little from the practices employed with mild steel, it may be of interest to present certain generalities which have been evolved to serve as a guide to the fabricator. While these cover many of the phases of railroad car construction particularly, they can be applied equally effectively to the fabrication of nearly all types of equipment.

COLD FORMING OR PRESSING

The high-tensile steels are somewhat stiffer than the plain low-carbon steels and would require a greater force to produce permanent deformation were the thicknesses to remain the same. However, the use of these steels will result in thinner sections thus reducing the force required. In general, the only departure from regular practice is with respect to the bending radii, as follows:

(1) Material up to $^1/_4$ inch in thickness should be bent over radii of not less than one and one-half the thickness.

(2) Material $^1/_4$ inch thick and up to $^1/_2$ inch the radii of bends should not be less than two times the thickness.

(3) Sharp fins or burrs from shearing should be removed by filing or other satisfactory method prior to cold forming.

It is generally advisable to allow for somewhat more spring-back in cold pressing these steels, particularly where the radius of bend is fairly large. The alloy steels also do not have the same upsetting ability and tend to fold over. This can sometimes be corrected by corrugating or crimping or removal of metal from the edge to be shortened. Slower forming speeds enable the metal to flow better and smooth dies are helpful.

HOT FORMING OR PRESSING

Material up to and including 1 inch in thickness should be heated to a uniform temperature between 1400° and 1650° F., or visually, at least to a good cherry red prior to pressing or forming, with no work being done on the material after it has been allowed to cool to a temperature of 1000° F. or a dark heat. Bending radii should be not less than one and one-half times the thickness of material.

SLOTTING AND COPING OPERATIONS

(1) Slots in framing members for gusset plates should have radii at ends of slots not less than one-half the width of slot.

(2) All copes and large slots to have radii in corners of not less than two times the thickness of material.

(3) On side of framing member slotting tool die, a radius slightly larger than the radius in framing member should be provided to insure member being flat on the die, to avoid deformation and cracking.

(4) In case of angle of cope being reentrant and exceeding 90°, it is recommended that a hole be punched or drilled in the corner to help avoid cracking in bending.

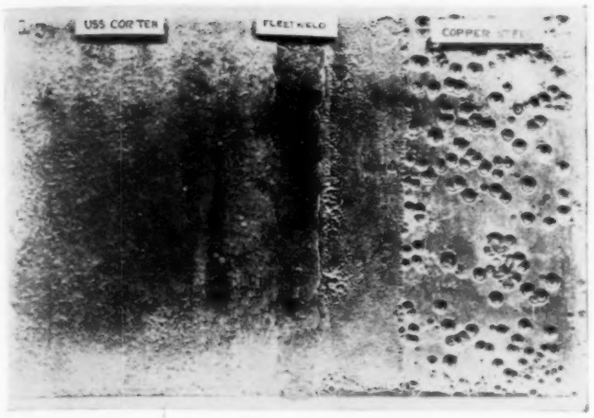


Fig. 10—Corrosion Test of Copper Bearing Steel Welded to Cor-Ten

MANUAL METAL ARC WELDING

(1) Use the smallest possible electrode, compatible with the thickness of the material, so as to avoid excessive weld beads.

(2) Carefully fill up all craters to eliminate leakage. High-grade mild steel coated electrodes are generally satisfactory for use with high-tensile steels as there is generally sufficient "pick up" from the base metal and sufficient reinforcement to produce adequate strength in the welds. However, if conditions require it, rods can be obtained to produce weld-metal similar in analysis to the base metal.

STRAIGHTENING OPERATIONS

(1) Cold straightening of parts should be done at room temperature or at least below 250° F. Rest blocks should be properly spaced in all press straightening to insure sufficient leverage so as to avoid shearing action. Use of Flatter is important in all sledge or hammer straightening.

(2) Hot straightening of all the larger mass sections should be done at a temperature of 1400 to 1650° F. Either furnace or torch method of heating may be employed but no work should be done after material has reached a temperature of 1000° F.

TORCH OR FLAME CUTTING

Cutting by this method should be done with the smallest size tip practicable. The use of a larger tip should be avoided so as to provide a smooth clean cut with a minimum tendency for the metal to flow together back of the cut.

STRESS RELIEVING

This operation is to effect exactly what the term implies, that is, to relieve stresses set up from welding, severe forming or pressing. For this purpose a temperature of 1250 to 1350° F. should be ample for Cor-Ten and about 1150 to 1250° F. for Man-Ten. The stress relieving will slightly lower the original tensile properties of the material.

SPOT WELDING

Material in the form of sheets for spot welding should be pickled and oiled to provide surfaces free from scale which would otherwise interfere with the proper passage of the current. If flatness is required the sheets should be stretcher leveled.

CORROSION RESISTANCE

Reference has been made briefly, in the foregoing paragraphs, to the corrosion resistance of the low-alloy high-tensile steels. The curves in Fig. 9 illustrate the comparative resistance of Cor-Ten steel, and regular copper bearing steel when subjected to a severe industrial atmosphere for three years. It will be noted that in the short initial period of exposure the rate of corrosion for the two materials is approximately equal. However, as corrosion progresses, the protective film which forms on Cor-Ten retards the rate of corrosion and over a longer period a superiority of more than two times is found in the resistance of this grade.

In the application of the low-alloy high-strength steels it sometimes is necessary to join these materials by welding with plain steel and the question has been asked as to the possible extent of electrolysis when the dissimilar analyses are joined in intimate contact.

The USS High-Tensile steels, however, and particularly the Cor-Ten grade, are dependent for their greater strength and superior properties not so much on the total per cent of alloy content as on the proper balance of several elements in correct proportion. In other words, the total alloy content of these grades is relatively low and an extremely slight differential in electrical potential is found. Figure 10 represents a sample of Cor-Ten steel welded to plain copper bearing steel with mild steel electrodes. The weld bead was ground flush with the base metal and the sample exposed to running mine water of a high acid content for 108 days. The severity of the attack can be noted by the extent of pitting on the copper steel sample and yet no zone of electrolytic attack is noted on either of the two steels adjacent to the weld bead.

CONCLUSION

It is realized that a paper on the broad subject of high-tensile low-alloy steels must of necessity treat the subject in a rather brief manner, but it is hoped that the examples selected will indicate the varied and extensive way these steels can and are being used to effect reduction in weight, increased life or durability or greater strength without reduction in weight. It has also been the aim to present certain comments and observations in connection with the use of these steels which may prove helpful to those engaged in the same or similar lines of endeavor. To every one in manufacturing industry, however, the high-strength steels will be found worthy of interest.

RESULTS ACHIEVED BY Qualification Tests of Marine Welding Operators

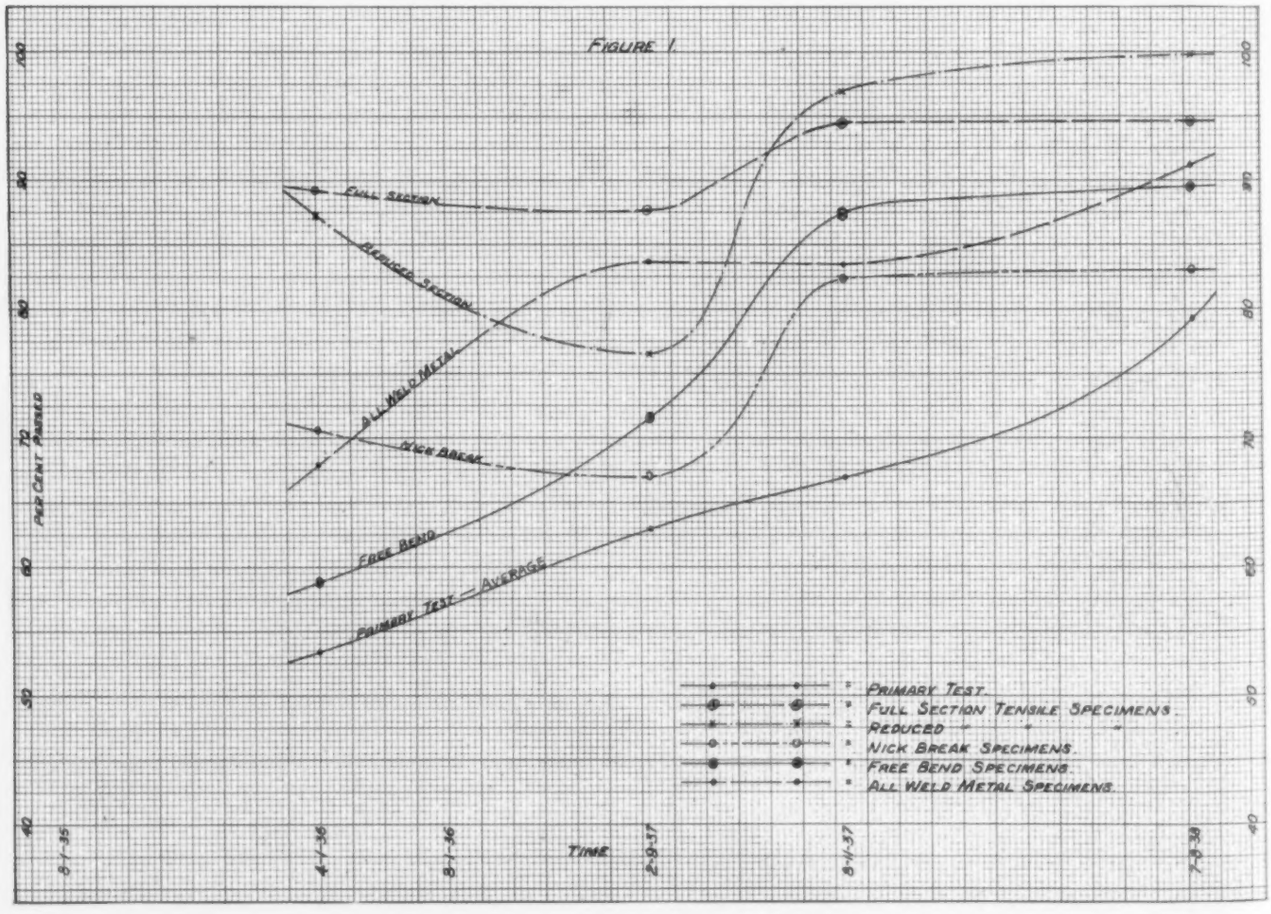
By JAMES W. WILSON†

THE Bureau of Marine Inspection and Navigation, in applying its code where fusion welded construction is involved, has followed the recommendations of the A. W. S. Committee on Welding in Marine Construction. The tentative rules formulated by this Committee include definite requirements for the qualification of individual welding operators and it has been the practice of the Bureau to carry out such qualification of operators by testing specimens from sample weld plates made by them. The procedure that has been developed in the testing of such qualification specimens has revealed some extremely interesting information concerning the characteristics of welding operators and the tendencies of the manufacturers or contractors by whom they are employed. The following information is presented with a view to showing the beneficial effect which this testing procedure has had not only upon the welding organization itself but also upon the work of the Bureau and the resulting safety of the public in general.

The desire of the Bureau is that in qualifying welding operators they shall be tested with a view to determining their ability to produce sound welds and obtain complete penetration. The Bureau has followed the tendency of the A. S. M. E. Boiler Code Committee by placing the responsibility for the quality of such welds in the hands of the manufacturers or the contractors. While it may be the intention of the manufacturers and contractors to produce sound and dependable welds, nevertheless there is an element of human responsibility carried by the welding operator and this it has been the desire by the Bureau to check in the most effective possible manner. It has been the experience of not only the Bureau but of other law enforcing bodies that if a welding operator is found to be capable of producing sound and dependable

† Senior Marine Engineer, Bureau of Marine Inspection and Navigation, Department of Commerce.

FIGURE 1.



welds, his tendency will be to produce welds of that character if given the proper materials and equipment. Therefore, while both parties carry a large measure of the responsibility for good work, it is obviously the necessity of the Bureau to test the work of each individual welding operator, as well as to regulate the manufacturer or contractor.

The average welding work in the marine field has not measured up to the results which could be achieved. This was in large part due to the fact that the volume of repair welding work fluctuates and a contractor who may need 50 welding operators in one month may only require 10 the following month; hence, it was formerly the practice to employ men who represented themselves as competent welding operators and to lay them off when the work was completed. This condition has been cured to a great extent at the present time by training the welding operators to perform other duties when there is no welding work to be done, thereby retaining men of proved ability to carry out welding work successfully when there is a rush; hence, the previous practice of employing welding operators intermittently, which caused inspectors much apprehension, has been largely eliminated.

In developing a testing procedure for the qualification of welding operators the Bureau decided upon simple tests intended to show the tensile strength and ductility of the material, the integrity of the bond between the base metal and the weld-metal, and to detect such defects as lack of penetration, non-metallic inclusions, porosity, etc. For this purpose the following test specimens were required.

1. A full section tensile test specimen (required under test to show a tensile strength at least equal to the minimum tensile range of the base metal).
2. An all-weld-metal tension test specimen, having a gage length of two inches in the reduced section and a diameter of 0.505 inch (required to show a tensile strength at least equal to the minimum range of the plate from which the specimen was prepared, and an elongation of not less than 20% in two inches).
3. One nick break test specimen having the edges of the weld nicked on each side to cause a clean break (required to detect defects such as lack of penetration, non-metallic inclusions, porosity, etc.). It was provided that a standard density specimen might be substituted for the nick-break specimen, if desired.
4. One standard free-bend test specimen (required to show an elongation across the weld of at least 30%).

The material of which these specimens were made, with the exception of the all-weld specimen, was required to have a minimum thickness of not less than $^5/_8$ inch and not more than 1 inch.

The specimens were required to be prepared in the presence of a duly authorized inspector and to be stamped by him for positive identification. Tests were required to be made by the Division of Engineering Mechanics of the National Bureau of Standards, with a view to having them made in a scientific manner by experts, thereby eliminating the possibility of faulty or biased testing in evaluating the welding operators' ability.

These rules which embrace the qualification requirements, were placed into effect in August 1935, but it required considerable time to instruct the district inspectors and provide for the preparation of the test specimens and their transmission to the Bureau of Standards in Washington, D. C. The latter Bureau was for a time heavily loaded with the burden of this test work and it was not until in 1936 that the results were forthcoming in sufficient volume to indicate the tendencies. These are so interesting that a graph has been prepared to outline them as illustrated by Fig. 1. This graph was plotted for the purpose of showing the percentage of failures for various periods after the tests were initiated to date. The lengths of the periods shown are not uniform and were taken at times when it was convenient to make a check on the tests. A study of the graph shows the improvement in the quality of welding since the tests first began, which is due very largely to the fact that both the employers and the operators were spurred by the failures to greatly improve their processes and procedures.

The graph is based on primary tests only and does not include retests of specimens for those who failed, nor requalification tests which are conducted annually. The lower line in the graph indicates the average results of the four specimens originally submitted by each welding operator and shows a general upward trend from the date the tests began, as the operators began to appreciate the seriousness of the qualification requirements.

The second line from the bottom, indicating free-bend tests, shows a gradual rise in the quality of the bend tests from April 1, 1936 to February 1, 1937. From that time on the curve takes a decided upward trend until August 11, 1937, after which time it tends to flatten out up to the present.

The third line from the bottom indicates that the results of the all-weld tests had a gradual upward trend from April 1, 1936 to February 9, 1937, and that after that time it flattened out until August 11, 1937. From that time it again takes an upward curve which continues up to the present time.

The fourth line from the bottom, indicating the nick break tests, shows a curve downward from April 1, 1936, to February 9, 1937. Then it takes a sharp upward trend to August 11, 1937, after which it flattens out up to the present time.

The fifth line from the bottom, indicating reduced section tension tests, shows the results of tests, which in some cases were submitted in lieu of the all-weld specimens. This curve shows a downward trend from April 1, 1936 to February 9, 1937. After that it curves sharply upward until August 11, 1937, at which time it tends to flatten out up to the present date.

The top line, indicating full section tension tests, shows a drop from April 1, 1936 to February 9, 1937, but not nearly so pronounced as the drop in the reduced section tension tests. Then it curves upward from February 9, 1937 to August 11, 1937, and from there it flattens out to the present date.

The full section tensile test specimens tend to show that in the beginning the welding operators, as was customary with some of the old-timers, endeavored to obtain high-tensile strength, paying little regard to the ductility and other characteristics of the weld deposits. The curves show that from April 1, 1936 to February 9, 1937, the tendency was to sacrifice high tensile strength for ductility and from that time on the improvement of the welding was general in all characteristics.

SUMMARY

Since the adoption by the Bureau of the welding qualification rules, the National Bureau of Standards has tested for this Bureau 7819 welded specimens for primary qualification tests. This does not include retest specimens or specimens submitted for specific gravity and requalification tests, as the number of specimens in the last two groups is so small as to be considered negligible for the purpose of this report.

The net results of these tests up to the present time show that at the time the tests were initiated only 52.5% of the welding operators were successful in passing the tests, whereas, at the present time over 81.5% of the welding operators pass their tests successfully.

There is no question that the quality of welding now performed is far superior to the welding available prior to the initiation of the tests, as a result of which it is now possible to make repairs with an assurance of their safety, which could not be assured before. It is gratifying to know that manufacturers and contractors have cooperated by training their welding operators thoroughly, supervising their work and eliminating those whom the tests prove are not competent to produce sound welds.

Reply to Dr. Jacobus' Discussion on Radiographic Inspection*

By HERBERT R. ISENBURGER†

THE author greatly appreciates Dr. Jacobus' comments. It is our business to point out important applications of radiography, but it is up to the engineers to determine whether a 100 per cent inspection is justified in each case.

Dr. Jacobus has mentioned welding of marine piping. In this connection it is interesting to know that the Navy Department is purchasing portable X-ray units for the Philadelphia and Brooklyn Navy Yards for this particular purpose, although the Navy has large amounts of radium available.

In other countries more so than in the United States, X-ray inspection has been used for the examination of other types of welded structures. Particularly in Germany, X-ray inspection is a great aid for what they consider important examinations. The State Railroads now make X-ray inspection mandatory in their welding specifications after they have had years of experience in field work (273).‡ In France the all-welded plate girder railroad bridge of Plaine-Saint-Denis near Paris was X-rayed last year (722), and Sweden found X-ray inspection most useful for similar work (748) as shown in Fig. 1. This photograph also shows that an X-ray tube can be placed in very cramped quarters, an objection raised by Dr. Jacobus. In fact, we find that wherever a welder can work we can get to, too.

Another important application is the examination of welded fuselage structures in airplanes. Practically all European aircraft manufacturers have been equipped with X-ray machines for a good many years. Some of the more recent experience has been described by Schmidt (694). In marine construction too, European navy yards are well-equipped with X-ray units. One of the first was the navy yard at Copenhagen. A few years later Wilhelmshaven followed with a large portable X-ray installation (417).

Much valuable information concerning the practical experience with magnetic-powder methods for weld inspection can be found in a series of reports from the

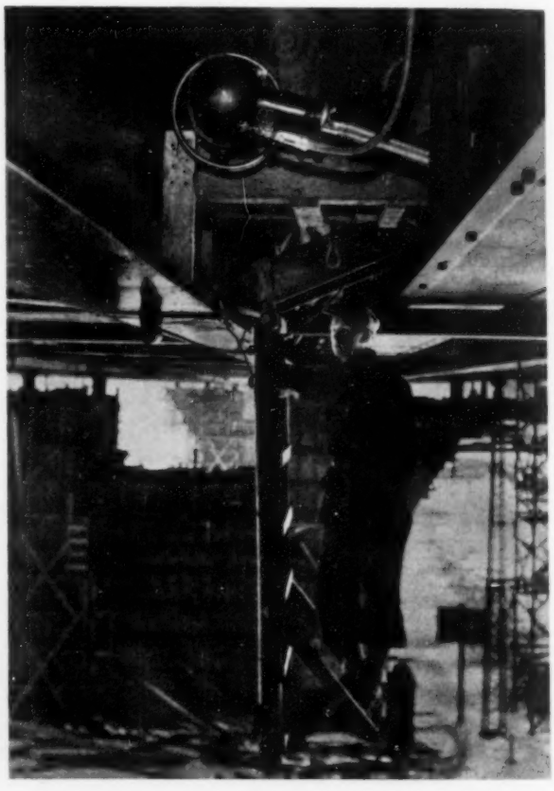


Fig. 1

Reich's X-ray laboratory.[1] They also discuss American practice.[2]

The author was especially interested in Mr. Carpenter's remarks concerning the use of radium for field-weld inspection, but regrets that he failed to indicate the quality of his results. Our experience checks with that of other independent workers in this field (501 and 433) and has been completely justified now by a statement of Mr. Hugo W. Hiemke, representing the opinion of the Bureau of Engineering, U. S. Navy, as follows: "Up to thicknesses of two inches the X-ray method is more sensitive, and requires much less time."[3] It is for this very reason that, as mentioned above, the Navy Department is purchasing X-ray equipment for the inspection of welded pipe joints.

Mr. Carpenter states in part: "No more portable X-ray apparatus than the present portable-tube types

* Published in August 1938 issue of THE WELDING JOURNAL.
† St. John X-Ray Service, Inc., Long Island City, N. Y.
‡ Numbers in parentheses refer to the Bibliography on Industrial Radiography by Herbert R. Isenburger, published by the American Documentation Institute, 2101 Constitution Ave., Washington, D. C., 1938.

[1] W. Schirp, "Results, New Possibilities and Limitations of Magnetic Testing Methods," *Stahl & Eisen*, **58**, p. 235, 1938.
[2] R. Berthold, "Magnetic-Powder Method Inspection in U. S. A.," *Mit. d. Ver. d. Grosskesselbesitzer*, **65**, pp. 370–371, 1937.
[3] Welding Handbook, A. W. S., p. 772, 1938.

has been devised." This is a statement of fact which is incorrect and misleading. We are using in practical work and have been using for two years equipment which goes everywhere the welder goes.[4] Our X-ray tube weighs about 100 lb. and the shield is only 30 inches long, whereas Mr. Carpenter's insert tube alone is 40 inches long. Other features of this tube and our compact unit have been described in the original paper (747) and in more detail elsewhere (760).

Since the original article was written about a year ago, we have had some additional experience which may be of interest. In one case which was reported to have required about 25 per cent repair, the second unit was welded by the same welders. Due to their previous experience and training under X-ray control, these welders had perfected their technique to such an extent that they were able to turn out perfectly sound and acceptable joints. Consequently, X-ray inspection could be discontinued. Again on another job which was done by crack welders, still quite a few welds needed repair.

The more experience we have and the more welding jobs we see, the more we are convinced that X-ray inspection is not only a valuable aid but a necessary tool.

[4] The Welding Journal, p. 9, July 1938.

The USE of ELECTRIC RESISTANCE Welding in the Automobile Industry*

By Dr. ARMAND DI GIULIO†

THE use of electric resistance welding as a method of joining metals together is considered a relatively new development; however, while it is true that resistance welding has received its greatest impetus in the last decade, the application of resistance welding in the automobile industry dates back 30 years or more. In the early days of the Model T, about 1907, resistance welding was tried in making the brake pedals, but, unfortunately, the first attempts did not meet with the success which had been anticipated. When we think back of the materials and the machines which the early

* Paper presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Assistant Professor of Metallurgy, University of Detroit, formerly Research Metallurgist, Ford Motor Company, Dearborn, Michigan.

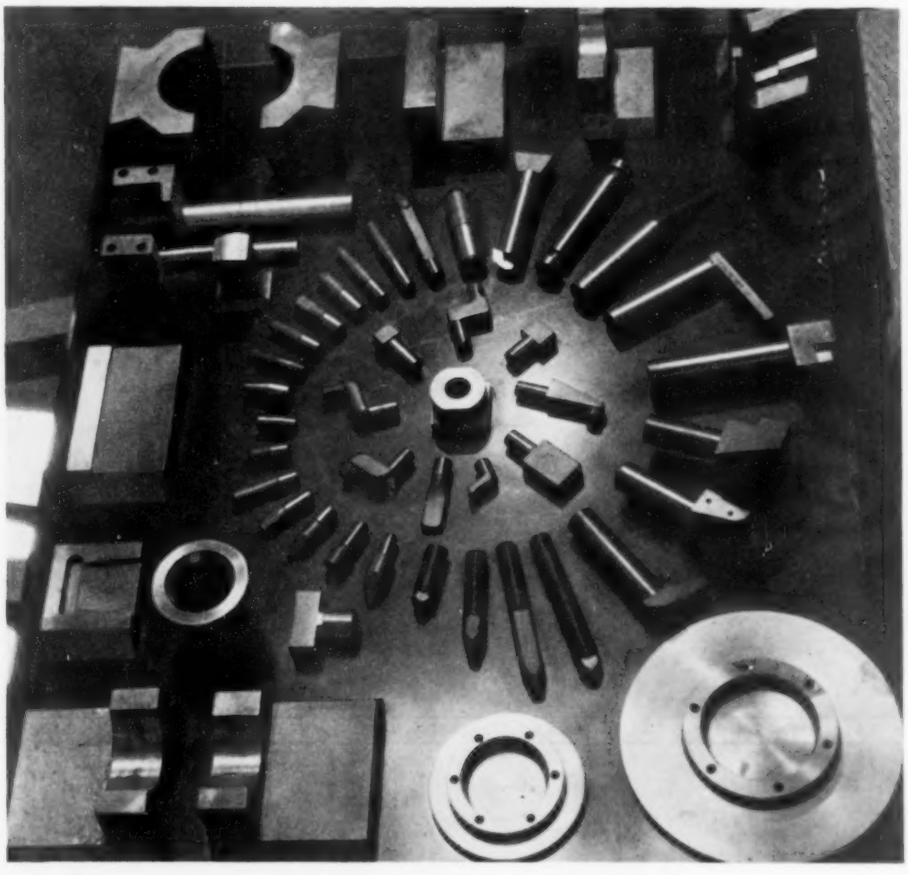


Fig. 1—Jaws and Electrodes for Butt Welders

Fig. 2—Ring Gear Before and After Welding Operation

welders had at their disposal, it is no wonder that the quality of the welds was relatively poor.

The industrial development, which took place during the World War period and in the years following, is generally responsible for the improvements brought about in the quality of the weld, and in the lower cost of production. A casual visit to any of the modern automobile plants will show that in the making of a car no other fabricating method is as extensively used as electric resistance welding.

Resistance welding, in all its variations, is essentially a new version of the old forge welding; that is, the union of the metal is accomplished by the combined action of heat and mechanical pressure. Thus, in resistance welding, one is confronted with some of the problems which confronted the blacksmith, and with the new problems brought about by the mechanization of the process.

IMPORTANT FACTORS

Briefly summarized, the three most important factors of resistance welding to consider are: (1) materials to be welded, (2) electrode materials and (3) pressure and current control.

1. *Materials to Be Welded.*—In any welding process, one must take into consideration the thermal and electrical properties of the metals to be welded, the changes in the properties of the metals at elevated temperatures and the structural changes which may occur while the metals are being heated. In the construction of automobile bodies, this problem is somewhat simplified because of the fact that the material is, in general, low carbon steel sheet. On the other hand, in engine parts, chassis parts and accessories, cases are found in which dissimilar metals are welded together. At times, the problem involves parts which must be subjected to heat treatment, in which case, phase changes or the formation of a new constituent, as the result of the heating to welding temperature, must be recognized. A typical illustration is furnished by the welding of stainless steel of the 18–8 type in which the heating to welding temperature, if not properly controlled, may cause carbide precipitation, which, in turn, lowers the corrosion resistance of the metal.

2. *Electrode Materials.*—The question of the proper electrode is unquestionably a very important one. First of all, the material must stand the load of the machine. The tip pressure in the case of a spot welder, or the pressure at the jaws of a butt or flash welder is at times very high. It is essential that the areas of contact between the work and the electrodes remain as constant as possible during the life of the electrode; hence, hardness is an important requirement of the electrode material. This, however, must not be taken to mean that the harder the better, for, together with hardness, the electrodes must possess other physical properties to withstand the repeated stresses, and to insure longer life.

In general, the physical properties of the electrode materials are greatly affected by the temperature. Loss of hardness and strength will occur during the welding cycle if the electrode is heated above a certain softening temperature. This is due to the fact that the cold worked alloy or alloys which have been age-hardened will undergo structural changes when heated. Electrode material must possess high electrical conductivity in order to localize the heating zone where it is most desired, and thus avoid sticking of the electrodes to the work. As is known, electrical conductivity decreases with increasing temperature; thus, in the case of spot welding, especially, it is of primary importance that the electrodes be provided with adequate cooling water. Many cases of electrodes sticking to the work can be traced to poor cooling. It is almost impossible to set a definite rule by which the depth of the cooking cavity can be established. In general, it can be stated that the closer the water can come to the tip of the electrode without impairing the strength of the point, the better will be the weld, and the longer will be the life of the electrode.

Standard spot-welding electrodes and jaws for butt and flash welders are generally made by machining, or by forging and machining bar stock of the alloy desired. The Ford Motor Company, however, has for the past 3 years very successfully used cast spot-welding tips and jaws. The casting process in the case of spot-welding tips, has materially reduced the amount of metal to be machined, and has permitted the casting of irregular shaped electrodes, which would require expensive forging dies. In the case of jaws, the Ford Motor Company has eliminated the use of hard-facing materials which required a brazing operation. In the three years of operation, the results obtained with cast electrodes amply justify their use. Figure 1 shows some of the spot welding electrodes and jaws for butt welders which are cast by the Ford Motor Company.

3. *Pressure and Current Control.*—It has already been mentioned that resistance welding invariably makes use of mechanical pressure in order to bring about the joining of the pieces. In all cases of resistance welding, and in particular in the case of spot welding, the control of the welding pressure is of great importance. The mushrooming of the electrodes necessitating continuous filing and repairing, is primarily due to the fact that, during the welding operation, the pressure applied exceeded the yield point of the electrode material at the temperature

Fig. 3—Fuel Pump Push Rod Before and After Welding Operation

of operation. Again, we see here how important is the proper cooling of the electrodes. If the temperature at the tip is not allowed to rise, the yield point of the material is considerably higher and the application of the pressure will not cause the metal to flow.

In exterior parts of a car which have to be enameled or finished with other protective coatings, it is essential that the surface be smooth to avoid costly polishing. For this reason, the impression left by the electrodes should be kept at a very minimum; thus, it is important that, particularly in spot welding, the pressure and current cycles be synchronized. For this purpose, there are several types of timing mechanisms: (*a*) manually operated switches, (*b*) electric relays, or (*c*) electronic control. Regardless of the type used, it is important that the proper synchronization between pressure and current cycle be maintained so as to assure the uniformity of quality which is necessary for production operation.

TYPICAL APPLICATIONS

In order to present some typical illustrations, let us consider briefly the more important applications of resistance welding in the three main parts of the car; namely (1) engines, (2) chassis and (3) body.

1. *Engine*

First of all, in the engine, we shall consider the making of starter ring gear.

(*a*) *Starter Ring Gear.*—The starter ring gear requires the welding of the rim blank. This operation is carried out in a flat top flash butt welder having a transformer of 100 kva. capacity. The ring blank is $^3/_4$ inch x $^3/_4$ inch and the steel used corresponds to Ford Specification for EEE Steel, which is similar to S. A. E. 1045. The gripping of the ring in the jaws is hydraulic, and, while the preheating cycle is manually controlled, the final step is automatic. In this operation, we are able to maintain the burned out material to $^1/_2$ inch and the upset to $^1/_8$ inch. After welding, the ring is annealed at 1300° F. for 50 minutes and is ready for the gear cutting and the final heat treatment.

(*b*) *Fuel Pump Push Rod.*—The fuel pump push rod, composed of three parts is assembled by means of spot welding. The machine used is a standard spot welder which utilizes a spring system for the application of pressure. The electrode is specially shaped at the tip so as to conform to the contour of the rod and in one operation a continuous weld is made joining the three pieces together. Figure 2 is a photograph showing the ring gear and Fig. 3 the fuel pump push rod before and after the welding operations.

(*c*) *Fly Wheel Pulley.*—The fly wheel pulley is made of three parts, the flange, the rim stamped from hot rolled sheet steel 0.074–0.082 inch thick, and the hub which is made of a free cutting steel. The operations are as follows: first, the flange is spot welded in four places on the hub with a Standard Spot Welder equipped with a 40 kva. transformer, next, the rim is spot welded in six places to the flange in a standard spot welder using a 80 kva. transformer. In both of these operations, the welding is done under a stream of water in order to keep the electrodes cold. Figure 4 shows the parts and the assembled pulley.

(*d*) *Oil Pan.*—The part in which resistance welding finds its largest application is the oil pan. The pan is made of 15-gage material hot rolled, oiled and pickled which is rough formed, then normalized at 1700° F. in a non-scaling furnace, followed by a restrike operation which forms the contour. Without going into actual detail in the assembly of the pan, I shall say that use is made of projection welding to fasten the drain bushing to the bottom, to weld the tapping nuts to the fly wheel housing reinforcement, and in fastening the oil retainer to the pan. In the cases, the welders are hydraulically controlled. Single spot welders are used to weld the baffle plates to the pan, and the starter plate to the fly wheel housing. In attaching the fly wheel housing to the pan, a spot-welding machine with a transformer of 100 kva. and air operated controls, allows three welds to be made at once.

Fig. 4—Parts and Welded Fly Wheel Pulley

2. *Chassis*

In the chassis we find several applications of resistance welding.

(*a*) *Torque Tube.*—In the case of the torque tube, both the flange and the ball ends are welded to a standard flash butt welder in which air pressure is used in clamping the stock and the other welding is hydraulically controlled. The transformer is a 350 kva., the stock used for the weld is $^1/_2$ inch and the upset is $^3/_{16}$ inch. The time required for each weld including loading and unloading the machine is about 30 seconds.

(*b*) *Drive Shaft.*—In making the drive shaft, both the male and female splines are welded by means of a Standard flash butt welder with 100 kva. transformer.

(*c*) *Radius Rods.*—Another application is found in the assembly of the radius rods. These rods consist of tubular section at the end of which steel forgings are welded. The right and left foot are forged S. A. E. 1040 which have been quenched and drawn before welding. The yoke of the rods is also a steel forging of a composition similar to S. A. E. 1030. These weldings are made in a Standard flash butt welder in which the clamping mechanism is air controlled, and the final pressure is mechanically applied.

(*d*) *Gas Tank.*—Seam welding finds its use in the fabrication of the gas tank. In this case, the material welded is terne plate. The operations are carried out in a series of welders. The water cooled electrodes used on this operation are made of forged copper which, in this particular application, has proved to be the most successful material primarily because it has very little tendency for sticking to the terne plate, and also because of its relatively low cost.

3. *The Body*

The greatest application of resistance welding in the making of a Ford car, is found in the assembly of the body. It is common knowledge that the quieter, safer and larger bodies of the present car could not be economically built if resistance welding were not used. Resistance welding has permitted the joining of many parts into one assembly which formly were held together by bolts and nuts. The rattling noises have been eliminated thus adding to the comfort of the passenger. Bodies have been made lighter and structurally stronger increasing in this manner both efficiency of operation and safety.

The variety in design of welding machines used in the making of the bodies is quite large, and generally depend on shape and size of the parts to be joined. It is opportune to mention that the tendency is toward the use of the multiple type of machines by which many welds are made at once. Also the use of the gun welder has brought the welding machine to the work instead of carrying the work to the stationary welder as was formerly done. Resistance welding in this case has reduced the use of arc and gas welding, and has resulted in cleaner and safer working conditions.

(*a*) *Steel Top.*—Typical application of resistance welding is the assembly of the steel top. The fixture used is made up of 6 gun welders with which 4 operators, after clamping the various parts, weld together with spots 2 inches apart the following:

1. The drip molding
2. The ventilator frame
3. The back window
4. The windshield frame assembly.

(*b*) *The Door.*—The assembly of the door also shows the extensive application of welding. In this case, the three pieces of the frame are welded together in a Standard flash butt welder with hydraulic clamping and automatic upsetting. Next the regulator panel is welded to the frame in a multiple spot welder by which 42 welds are made at the same time. This multiple transformer machine uses electronic control for the current cycle. The next step is welding of the glass retaining channels by means of projection welds, 6 in each channel. The machine used is a hydraulic with a 125 kva. transformer. Finally, the outer panel is welded in a hydraulic spot welder which also makes use of electronic control for the current; it uses 6 transformers rated at 400 kva. and makes 32 spots.

(*c*) *Final Assembly.*—The final assembly of the body such as the joining of the top and side panels, floor pan and dash is done by means of hydraulically controlled gun welders.

CONCLUSION

From this brief survey, one may safely deduce that in the future with the combined efforts of the Welding and Metallurgical Engineers, resistance welding will find greater application in the manufacture of better and more economical automobiles.

ACKNOWLEDGMENT

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Statement of the Ownership, Management, Circulation, etc.

REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AND MARCH 3, 1933

OF THE AMERICAN WELDING SOCIETY JOURNAL, published monthly at Easton, Pa., for October 1, 1938.

State of New York } ss.
County of New York }

Before me, a Notary Public in and for the State and County aforesaid, personally appeared William Spraragen, who, having been duly sworn according to law, deposes and says that he is the Editor of the AMERICAN WELDING SOCIETY JOURNAL and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

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Sworn to and subscribed before me this 21st day of September, 1938. (Seal) MARY T. HICKEY

Notary Public, New York County Clerk's No. 134.
New York County Register's No. 0-H-133.

(My commission expires March 30, 1940.)

WELDING in the CONSTRUCTION of Cranes and Power Driven Excavators

By H. C. HETTELSATER*

THIS discussion of the subject of the application of arc welding to the construction of cranes and excavators will deal mainly with the mechanical and structural features of design involved, and the effect of the use of this process on the product as well as the commercial and economic factors involved.

Illustrations of the application of welding are included to show the degree to which this process has been applied to the manufacturing of these two types of equipment during the last eight or ten years.

The entire material handling machinery industry, of which cranes and excavators form an important part, has been passing through a period in which revolutionary changes in design have been made in order to keep abreast of the present-day trend of eliminating excess weight in all types of moving machinery. These redesigns, which had their inception in a desire to reduce weight, also had for their object a reduction in manufacturing costs which would permit of offering the users of these types of equipment outstanding values, both in first cost and in operating costs.

In many respects the design changes have paralleled the recent developments in the automotive field where by consistent research and by development of new and stronger materials, it has become possible to produce the present-day automobile and truck, with its remarkably low cost and its extremely low operating and maintenance costs compared with the products of ten years ago.

The recent developments in the railway field have also spurred on the builders of cranes and excavators to doing a comparable job of adapting these new materials and processes to the building of their products. New materials, such as low-alloy structural steels, have been developed for use in railway equipment, and these same materials have been found to be very useful in the building of excavators particularly. Their use has resulted in very pronounced weight savings and a definite increase in the payload which can be carried.

The carrying of excess weight in an overhead traveling crane is expensive to its user in two ways. First, in the relatively high cost of the crane due to its higher material cost, and second, due to the fact that the excess weight in the crane trolley and girders must be carried on the crane runways. These runways are often many hundreds of feet in length, and very substantial savings can be made in the cost of construction of factory buildings if the cranes are designed to take advantage of the economies in weight which are possible by an extensive use of welded steel construction.

Figure 1 is shown to give a general idea of all welded steel construction as it has been perfected in overhead cranes.

The girders, end trucks, trolley frame, operator's cage, gear cases and platform are all welded. The over-all weight of this crane is from 10 to 15% less than it would have been if cast and riveted construction had been employed.

Excavating machines also offer extensive opportunities for the application of welded design. The machines under discussion are of the portable type, mounted on Caterpillar crawlers.

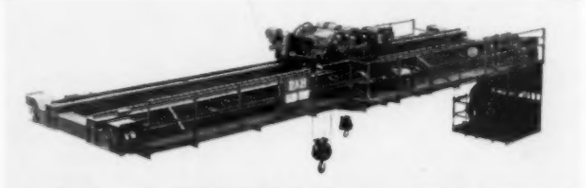
Figure 2 has a unit welded upper machinery frame, and also a unit welded lower frame in which all members which carry heavy bending stresses are of structural alloy steel. This is the first excavator of this size which has both the upper and lower frames of welded construction. This machine set up to handle a $2^1/_2$-yard dragline bucket weighs substantially less than the previous design of dragline which was built with cast steel base plate and car body. Most of the reduction in weight is due to the economies in weight which are traceable to the use of welded construction in place of castings, and to a careful distribution of machinery weight, so that the overhanging loads could be properly counterbalanced.

The bucket is of all-welded alloy steel, made as light as possible and still stands up under the work to be done. The boom is of alloy steel, with frequent supports to reduce the bending stresses due to the dead weight of the boom.

Excavating machines carry an over-hanging boom which carries the dipper or bucket, or which carries the hook for lifting crane loads. This boom is always in an

* Executive Engineer, Harnischfeger Corp.

Fig. 1—A Standard Type H-Crane 10-Ton Main Hook and 3-Ton Auxiliary Capacity



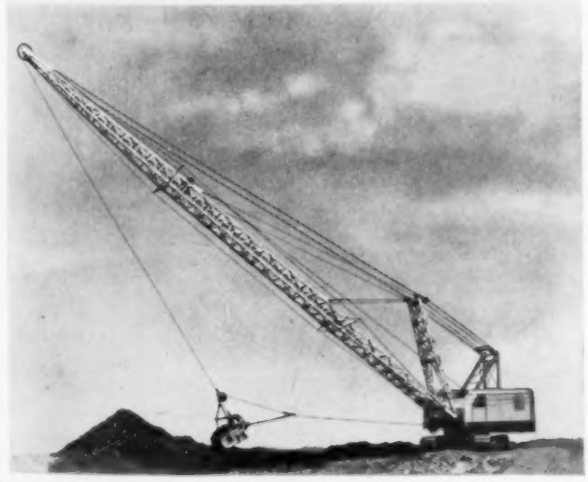


Fig. 2—An Example of an All-Welded Excavator. A $1^1/_2$-Yard Dragline with 100-Foot Boom

Fig. 3—All-Welded Trolley Side for Heavy Duty Crane

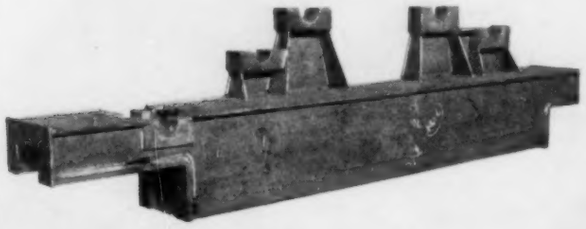
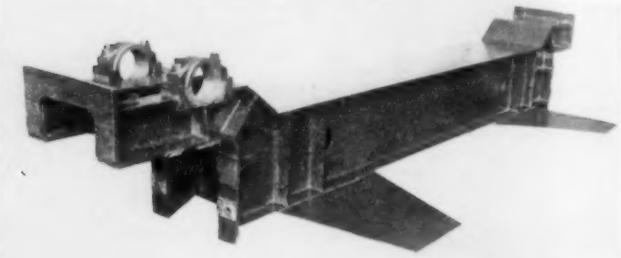


Fig. 4—A Typical Rolled Steel and Welded End Truck for a Crane



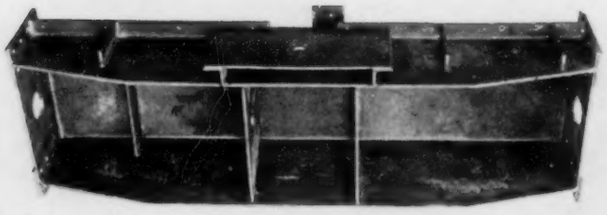


Fig. 5—A Typical Example of a Welded Trolley Cross Girt for Carrying the Main Load

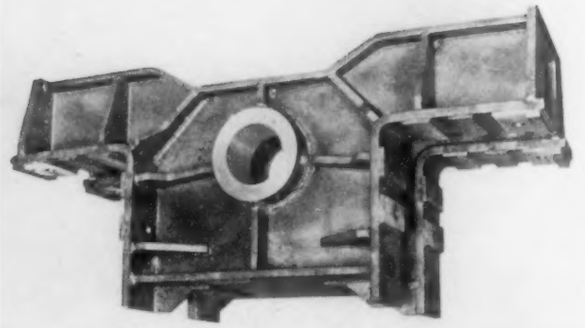


Fig. 6—Welded Equalizer Frame

over-hanging position and the boom, bucket and load must of necessity be suspended outside of the supporting frame. Therefore, it is extremely important that as much excess weight as possible be eliminated from the boom and bucket or dipper, since every pound of weight at the point of the boom must be counterbalanced by approximately five pounds in the main part of the machine. This fact has led to a very extensive use of welded alloy steel in the building of excavators.

The economic pressure which was brought to bear on this industry in the early years of the depression hastened the adoption of arc welding as a production method. The perfection of welded designs and also of the methods of fabrication advanced rapidly until now it can be said without fear of contradiction that the use of arc welding and alloy structural steels in the construction of cranes and excavators has definitely passed out of the experimental state, and is here to stay.

The early applications of arc welding were made for the principal purpose of eliminating pattern costs and resulted in the substitution of welded steel parts in place of cast steel and cast iron in a number of minor parts. This was especially true in the crane industry and also in the heavier classes of excavators, which are not produced in large quantities. These early attempts to introduce welded construction were handicapped by the fact that shielded arc electrodes were not fully developed, and as a result, the application of welding was confined largely to parts which were not subjected to very great impact loading.

When the shielded arc electrodes became generally available, it was possible to broaden the scope of welding applications in both the crane and excavator industries, and to include as-welded parts many machine and structural items which were subjected to shock and impact loads. This included such crane parts as trolley frames, girts, truck frames, end trucks and gears.

Figure 3 shows a typical example of an all-welded trolley side for a heavy duty crane. Note that the bearing brackets are welded as an integral part of the frame. The bearing blocks are solid billet stock. The main section is bent into a U shape and the top plate welded on last to close up the box section.

With bearing brackets all assembled as a permanent part of the frame, it is possible to machine all bearing fits in one setting, assuring accuracy and proper alignment of shafts.

Figure 4 is a box section, all welded. By welding all connections, it was possible to omit all connection angles, and as a result the weight was reduced 10 to 15% as compared with the previous design which was riveted structural steel. Note that bearings are welded in place as a permanent part of the frame.

The raised ends for bearing seats provide ample section for heavy wheel loadings with integral line shaft bearing brackets.

The wide cover plates and rigidly attached gusset plates assure a permanently aligned crane bridge.

This unit in Fig. 5 is designed for bolted connections to the trolley sides. Some of the trolleys are built with the girts welded to the trolley sides, but this cannot be done on the wider trolleys on account of shipping clearances.

This equalizer frame in Fig. 6 is used on 8 or 16 wheel cranes. The all-welded construction allows for flexibility in design since no pattern charges are involved in making changes to meet varying load conditions.

Most of the parts referred to were redesigned for welded construction without radically changing the shape or appearances of the part. This was largely due to a lack of experience on the part of the designer, and also due to a lack of equipment in the shop for forming and cutting heavy plates. Even in spite of these handicaps it was possible to make substantial weight savings.

During the year of 1934 great forward strides were made in the application of arc welding to cranes, and to excavators in particular. The experience which had been gained in the earlier years in fabricating parts which were largely copied after parts previously used, had by this time given the designers and welding technicians

sufficient information to enable them to embark on a program of redesigning parts and also complete machines so that arc welding could be applied to the best advantage.

One of the first steps was the building of gears for cranes and excavators of all-welded construction in place of cast steel. In the crane business especially, the use of cast steel gears presented a difficult problem because of the great number of different sizes of gears required to meet the varying speed demands. This entailed very high pattern costs and delays in producing castings. To meet this situation, welded gears were developed which would be interchangeable with cast gears and it was found by experience that welded gears could be produced at a very substantial saving as compared with cast steel gears. A few typical examples show that a gear $15^1/_2$-inch P.D.—4 D.P.—$2^1/_2$-inch face, made from cast steel weighed 99 lb. A welded gear which was interchangeable with this gear, and of a greater load carrying capacity weighed 75 lb.

Another example of a larger gear, 24-inch P.D.—3 D.P.—3-inch face weighed 196 lb. as a cast gear and 171 lb. as a welded gear, a saving of 13%. These examples are typical of what can be done along this line.

There are other distinct advantages to be gained by substituting welded gears for cast steel gears. It is possible in a welded gear to select the most suitable grade of material for each part of the gear. For instance, the rim can be made of relatively high-carbon steel which offers greater resistance to wear in the teeth, and the web and hub can be made from softer grades of steel which are readily machined, and which have relatively higher ductility. This opportunity for selecting the best suited material for each component part of the gear is one of the most important factors responsible for the savings which have been obtained.

The center of the welded gear in Fig. 7 is a steel casting secured to web by welding. The rim is made of S.A.E. 1040 steel, the balance of rolled steel is of mild steel plate. Welded gears have averaged 15 to 20% below interchangeable cast gears in weight.

Note that the web reinforcing rigs in Fig. 8 are made of bent plates. This makes a stiffer rib than a vertical plate with no increase in the amount of welding.

Most of our welded gears are made with S. A. E. 1040 steel in the rim, and low-carbon steels for the web, ribs and hub. The connecting welds between the web and the rim are of either two or three passes, and the entire gear is always stress relieved before machining.

About this time (1934) the various steel companies introduced their high-tensile alloy steels to the trade. These types of steels are what is known as low-alloy steels and were made available in plates, bars and structural shapes. The yield point of these alloy steels varies from 50,000 to 70,000 lb. per square inch, and the ultimate tensile strength varies from 65,000 to 95,000 lb. per square inch, depending on the type and grade of steel selected. The comparable figures on carbon steels are yield point 35,000 lb. and an ultimate tensile strength of 60,000 lb. minimum. It is, therefore, apparent that the substitution of alloy steels for carbon steels will permit a reduction in sections of from 30 to 50% while still maintaining the same factor of safety.

Due to the widely varying load and service conditions existing in the various parts of an excavator, it has been found advisable to adopt several different grades of alloy steels in order to cover the range of applications.

For example, for shovel dippers and for dragline buckets we use an alloy steel which presents the greatest possible resistance to abrasion. For this service we prefer steels with a carbon range from 0.35 to 0.50 and manganese from 1.25 to 2.00. In welding these classes of steel, it has been found to be advisable to use a welding electrode which produces a metal of about the same physical properties as the parent metal. By so doing, the designer can depend on the joints being as good as the rest of the unit.

The dipper in Fig. 9 is constructed entirely of rolled alloy steels with the exception of the cutting lip, which is a manganese steel casting.

The use of welded construction in this size of dipper resulted in a weight reduction which was sufficient to

Fig. 7—Welded Gear with Clutch Center

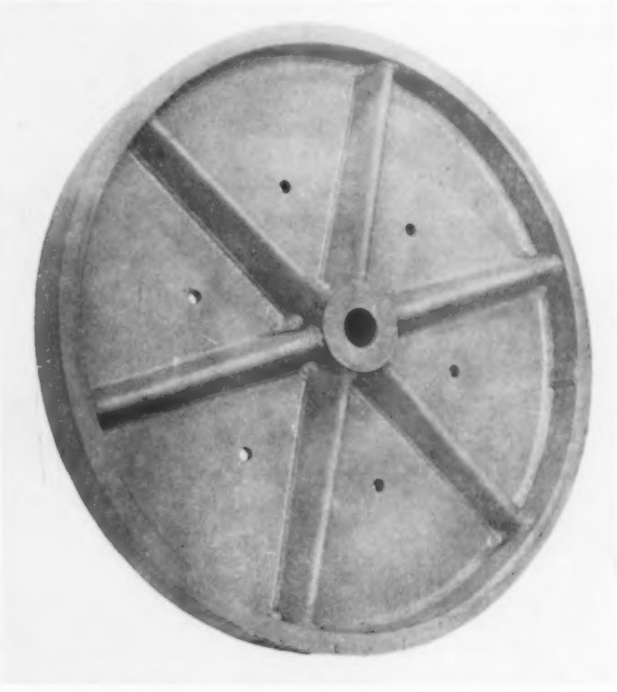


Fig. 8—Another Example of a Welded Gear

Fig. 9—A 5-Yard All-Welded Shovel Dipper for Handling Iron Ore

Fig. 10—A Typical Example of an All-Welded, Alloy Steel Dragline Bucket

allow for an increase of from $^1/_2$ to 1 cubic yard of payload without an increase in the size of the shovel.

Shovel dippers made from welded alloy steel with cast manganese steel used only for the actual cutting lips, are being used very extensively to replace the all cast manganese steel dippers which were previously considered standard for shovel service. A few typical examples of the weight savings will serve to illustrate the advantages gained.

A 1-yard welded dipper with manganese lip weighs about 25% less than a cast manganese steel dipper. This saving is the equivalent of $^1/_4$ yard of pay load.

Over a range of sizes from $^1/_2$-yard capacity to 5 yards, the average weight saving which has actually been made is 25%. There are now several hundred of these welded dippers in use which are giving very satisfactory service.

Welded alloy structural steels have been generally applied to other parts of excavator front end attachments such as dipper handles, shovel and hoe booms, dragline and crane booms. The reductions which resulted from the use of welded alloy steels are of extreme importance because these parts are overhung outside of the supporting base, and their weight must be counterbalanced by weight in the machine itself.

Various other structural members such as lower frames for excavators and crawler frames have been economically constructed using welded alloy steel and the results have been very satisfactory. It must be pointed out in this connection that in order to obtain the full advantage of this type of construction, it has been found necessary to discard the old methods of design and oftentimes to radically change the shape of parts previously used, and select shapes and designs which are suitable for economical fabrication as welded parts.

In both the crane and excavator business, it was found desirable to combine as many parts as possible into one unit frame. This applies particularly to trolley frames for cranes, and main machinery frames and car bodies or lower frames for excavators. An outstanding example of this is in the main frame of an excavator. In the older types of construction this main machinery frame consisted of a cast base plate which carried two side stands and a number of cross stiffeners or separators. These parts were all made separately and fits were machined and parts were assembled by bolting.

Fig. 11—A Comparison Between an All-Welded Alloy Steel Underframe, and a Cast Steel Frame for the Same Capacity Excavator. The Actual Difference in Weight Between the Welded and Cast Car Bodies Shows a Saving of About 40 Per Cent in Favor of the Welded Frame

Fig. 12—Main Machinery Frame for $2^1/_2$-Yard Excavator. Note That the Bearings and Machinery Locating Points Are All Self-Contained, and That the Frame Is So Constructed That All of the Machining Can Be Done in One Setting. This Assures Perfect Alignment of All Machinery, and Is Assurance Against the Machinery Getting Out of Line Due to the Loosening Up of Bolted Connections

In the modern excavators all of these parts are combined into one piece of welded construction. This eliminates a large number of machined fitting points, and also assures alignment of bearings since all bearing seats can be machined at one setting.

In forming the plates for the combined side stands and base plate, the side stands are usually kept an integral part of the main bottom plate. This is not universally true, however, since at times this feature of the design is limited by the width of plate which can be obtained. In general it has been found economical to use bent plate construction in preference to making extra welded seams. This, of course, requires the use of a rather large bending brake to avoid the expense of hot forming plates. Bent plate construction, in which the main plate is bent into a U shape, is generally used in the building of steel trolley sides, trolley girts, side stands for excavators, axles for excavators, lower frames, shovel booms and many other parts which lend themselves to a box girder type of design.

The Harnischfeger Corporation produced the first all-welded excavator early in 1935. These were what were known as the Bantam weight machines and were built in $^3/_8$-yard and $^1/_2$-yard capacities. These models embodied radical changes in design and construction to take full advantage of the weight savings which could be realized by a liberal use of alloy steels and by all-welded construction in the dippers, dipper handles, boom, main rotating frame and in the car body.

The very extensive use of arc welding and alloy structural steels in these excavators resulted in weight savings of close to 25% as compared with previous designs of the $^3/_8$- and $^1/_2$-yard shovels which were built mainly of cast steel.

The same principles of redesign which were embodied in the Bantam weight excavators have since then been used in the redevelopment of the larger sizes of excavators produced by this Company. The full line of gasoline and Diesel driven excavators which range in size from $^3/_8$ yard up to 3 yards are now of the all-welded type. About seven hundred of the all-welded type of excavators are now in actual and successful operation.

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BI-METAL CONSTRUCTION OF High Temperature Steel Valves*

By E. R. SEABLOOM†

VALVE manufacturers are constantly confronted with metallurgical problems which the ever increasing operating pressures and temperatures impose upon materials that enter into valve constructions. Within a relatively short span of years the pressures and temperatures in steam power plants have risen from 100 pounds per square inch at 338° F. to 1500 pounds per square inch at 950° F. In the oil industry the rise has been even more phenomenal and cracking stills are now operating at pressures of 3000 pounds per square inch and temperatures of 1200° F. Both of these enterprises are contemplating further increases in pressures and temperatures, with a view toward inward improving thermal efficiency and greater output. Designs of equipment and materials for the 2500 pound and 4000 pound standards are now being worked upon with great fervor.

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† Research Engineer, Crane Co. Research Laboratories.

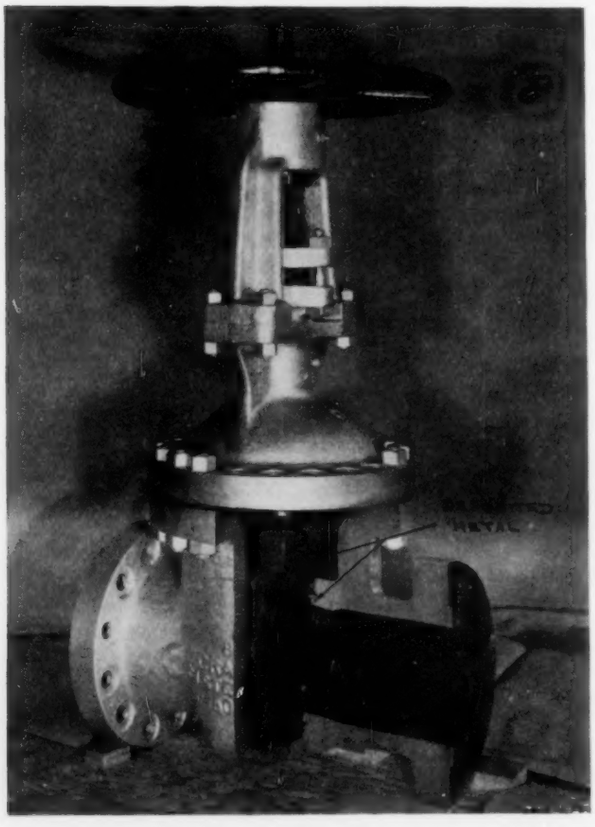


Fig. 1—Carbon Molybdenum Cast Steel Gate Valves with Deposited Seating Surfaces

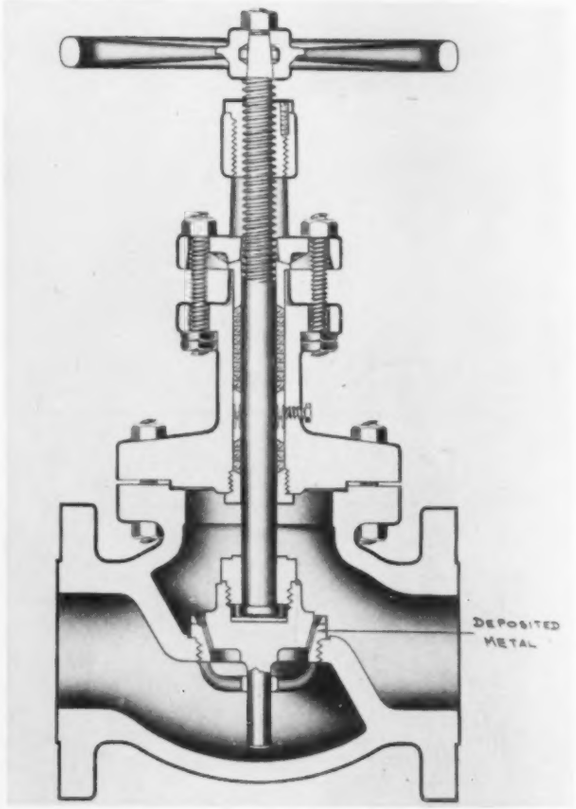


Fig. 2—Cross Section of Steel Globe Showing Deposited Seating Surfaces

During this period of evolution the materials of component valve parts have undergone rather rapid changes to meet the continuous advancement of operating conditions. The bodies and bonnets, which comprise the pressure-containing shells of valves, have changed from cast irons, malleable irons and bronzes to cast and forged carbon steels and numerous types of alloy steels. The alloy steels used are of both the low-alloyed types containing such elements as nickel, chromium and molybdenum, and the high-alloyed austenitic types, depending upon the specific service requirements. The internal valve operating parts have also undergone notable changes, especially the seats and disks, which are subjected to the most severe abuse. In the early days these were made from bronzes, but as pressures and temperatures mounted it became necessary to continually adopt other materials or combinations of materials such as monel metal, cast nickel-copper-tin alloys, alloy

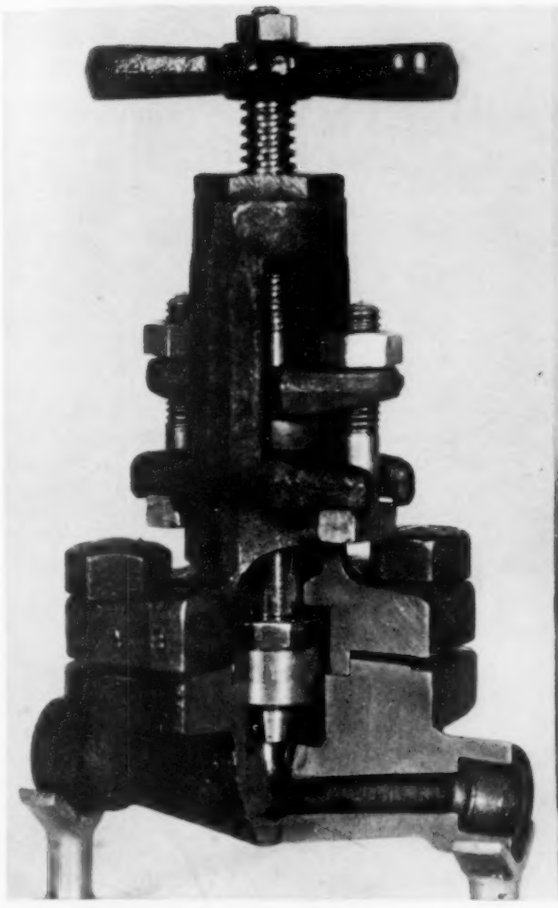


Fig. 3—Small Carbon Molybdenum Forged Steel Globe Valve with Integral Deposited Seat

Fig. 4—Gate Valve Disk Eroded on Steam Service

steels, nitrided steels, stainless irons and finally the present ultimate of deposited surfacing alloys.

The general practice, at least by our company, is to employ deposited surfaces on disks and seats of all valves used on steam temperatures above 750° F. Although numerous styles of valves are utilized in most piping installations, the bulk of production is in the gate and globe types, as these meet most requirements in controlling the flow of fluids. Consequently this paper will deal with the bi-metal construction of these two basic designs of valves.

A gate valve for high temperature service, as shown by Fig. 1, has a sliding wedge gate or disk, which, when closed by means of the threaded stem, seats against the body rings mounted in the body and forms a pressure-tight connection. The seating surfaces of the disk and body rings are of deposited alloy material, the base metal of these parts being of an analysis suitable for the particular service requirement that the valve is to operate under. The body rings are either screwed or welded into the valve body, the latter method becoming necessary on higher operating temperatures to overcome the difficulty of the body rings loosening in service due to differences in expansion and contraction between the rings and body. Gate valves are primarily intended for shutting off and starting the flow of fluid in a pipe line, hence they are generally kept in either the closed or open position.

A typical globe valve, illustrated by Fig. 2, has a cylindrical tapered plug disk with a screwed-in, a screwed-in and seal-welded or a welded-in seat ring on the larger sizes. The seating surfaces of the disk and seat ring are also of deposited alloy material, particularly on globe valves intended for service at elevated temperatures. On the smaller sizes of steel globe valves the seating material is sometimes deposited directly onto the body seat bore, thereby eliminating the seat ring, as pictured in Fig. 3. Globe valves are used quite extensively for controlling flow by throttling, or in other words the lift of the disk is varied to obtain the desired rate of flow.

SELECTION OF SEATING MATERIALS

In valve construction the selection of seating materials is of vital importance as these are subject to extremely severe service. In order for material to be regarded as satisfactory it should possess high resistance to erosion, abrasion and corrosion, withstand heavy loading without galling or siezing under high temperatures, and offer a fair degree of machineability, at least it must be readily ground and lapped. When the material is deposited it should flow out smoothly so as to minimize the amount applied and reduce the quantity of metal removed by machining or grinding.

One of the most salient properties that a seating material should have is high resistance to erosion as when valves are throttle or not tightly seated the velocity of the fluid flowing through the valve is increased tremendously, causing a serious erosive or "wire-drawing" action on the seating surfaces. Figure 4 shows damage to the seating surface of a gate valve disk caused by erosion in actual service.

Fig. 5—Nozzle Fixture for Steam Erosion Tests

Fig. 6—Steam Erosion Nozzles in Operation on 350 Pounds Steam

Until quite recently the practice of studying materials to resist "wire-drawing" was to install test valves on steam headers and keep the disks minutely opened from the seats so as to obtain high velocity steam flow. Correlation of test results was generally very difficult because it was almost impossible to control the velocity through the test valves accurately and the test periods required to show any definite results ran into months and even years.

After considerable experimentation with various methods of erosion testing a system was finally developed wherein quick and accurate results are obtained. A fixture, as shown in Fig. 5, was designed to hold metal specimens $1^1/_2$ inch in diameter and $^1/_4$ inch thick. The fixture is of a two-piece construction; the lower part or body encloses the test specimen and is threaded to receive the nozzle having a $^1/_{16}$ inch diameter orifice, the face of which is maintained at a distance of 0.005 inch from the surface of the test specimen. The upper end of the nozzle is provided with a steam connection. The jet of steam flowing from the orifice impinges upon the specimen and spreads out radially at high velocity through the restricted area, eroding the specimen as it escapes into the exhaust provided by drilled holes in the side of the body. Figure 6 shows four of these "wire-drawing" nozzles in operation.

The relative erosion resistance of various ferrous and non-ferrous alloys has been determined by this method. Figure 7 shows examples of test results of some materials. Classification of the metals in relation to erosive properties is accomplished by microscopically measuring the depths of the craters and by examining macrographs of the eroded specimens. The results shown in Fig. 7 were obtained by a one hundred hour test on 350 pounds saturated steam pressure. The macrographs are magnified approximately eighteen times.

These investigations have indicated that hardness is not an index of a metal's resistance to erosion. This is evidenced in the nitrided steels which have a hardness in the thousand Brinell hardness number range and offer low erosion resistance. The stainless irons and steels, while not particularly hard compared to the nitrided steels, display excellent resistance to erosion. In the case of deposited surface hardening materials it appears that alloys such as the cobalt-chromium-tungsten class give superior results over the cemented tungsten carbides or borides, even though there is a tremendous difference in hardness values. The poor resistance to erosion offered by surface hardening materials having hard particles suspended in a relatively soft ferrous matrix is due to the fact that the matrix itself has a very low resistance to erosion. From our observations it appears that erosion is probably the result of a combination of mechanical wear and corrosion of the metal surface by the fluid. That corrosion is a factor seems to be indicated by the excellent performance of stainless materials, which can be attributed to their high degree of corrosion resistance. Although numerous metals display superlative resistance to "wire-drawing" or erosion, they cannot always be used as valve seating materials because of their tendency to seize or "gall" when operated.

RESISTANCE TO SEIZURE

In selecting seating materials for valves with sliding disks, such as gate valves, it is of prime importance that they have good bearing properties and retain their hardness at elevated temperatures so as not to seize or gall when operated under heavy loads. During the opening and closing operations on high pressure valves the seating loads, caused by the line pressure acting on one side of the disk with atmospheric pressure on the other side, will exceed 20,000 pounds per square inch. If an improper material is used galling is bound to occur rapidly, as shown by Fig. 8, wherein a gate valve disk was only operated twice under test conditions on 350 pounds saturated steam with disastrous results. The seating material in this case was 12% chromium iron and is an outstanding one as far as steam erosion is concerned, but is not suitable to operate against a material of similar characteristics in steam valves where no lubrication is obtained by the fluid. When a dissimilar metal is used with this type of material the results are much improved. However, in oil refinery service 12% chromium iron is very satisfactory.

In order to determine the relative resistance of seating materials to galling, special test specimens are first subjected to a laboratory wear test in a machine as shown on Fig. 9, in which the sliding action of a disk in a gate valve is simulated, the materials on test being rubbed together with a reciprocating motion while under constant load and in an atmosphere of steam at the desired temperature. Figure 10 shows a series of test specimens which have been subjected to such a test, and Fig. 11 illustrates, in more detail, results obtained with deposited cobalt-chromium-tungsten alloy and 12% chromium-iron.

Materials which show definite promise in the preliminary laboratory experiments are further investigated in an actual service test by installing valves made up with these seating materials on a high-pressure steam line. The valves are then opened and closed either manually or by means of a motor operated mechanism, blowing the steam to atmosphere, thus imposing heavy loads on the seating surfaces. These operations are continued until the seating surfaces fail or until the materials have proved satisfactory.

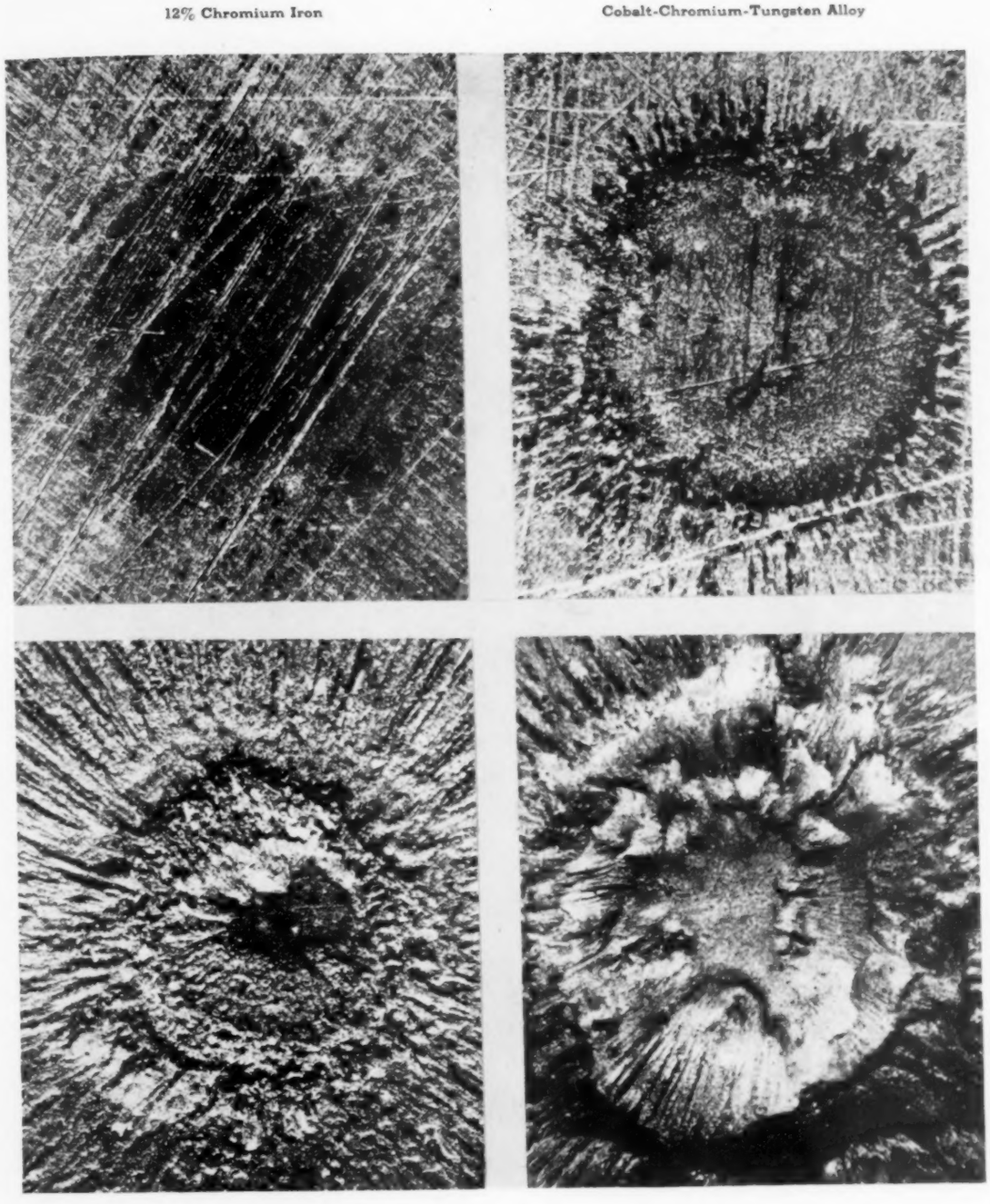


Fig. 7—Typical Test Results on Various Materials Subjected to Steam Erosion

RESISTANCE TO ABRASION

It is very desirable to use materials which have sufficient hardness to withstand scoring or indentation by scale and other hard foreign particles conveyed with the fluid which might become lodged between the seats during the opening or closing operations of a valve. The ability of a seating material to resist this action is a relatively simple matter to determine as this quality is primarily based on the hardness of the material.

NON-CORROSIVE PROPERTIES

Valves are often required to operate under both mild and severe corrosion conditions, depending upon the particular process in which they function. It is, therefore, necessary to make comprehensive corrosion tests upon materials which are being considered for seating surfaces in the laboratory under conditions that emulate those met in the various phases of industry. Figure 12 is an example of how seriously valve seating surfaces are

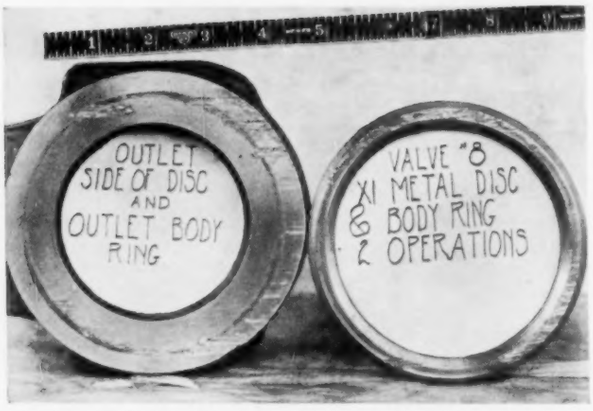


Fig. 8—Gate Valve Disk and Body Ring Damaged by Galling or Seizure of the Seating Surfaces on "Blow-to-Atmosphere" Test

attacked when subjected to very adverse operating conditions.

The final selection of materials for valve seats is usually a compromise as at the present time no particular alloy is outstandingly superior in all the desirable properties so as to make it universal in application to the numerous and varying conditions encountered in high temperature service. The materials chosen are the ones that meet most of the important requirements to give the greatest possible endurance for the particular design of valve and its function in a specific piping system.

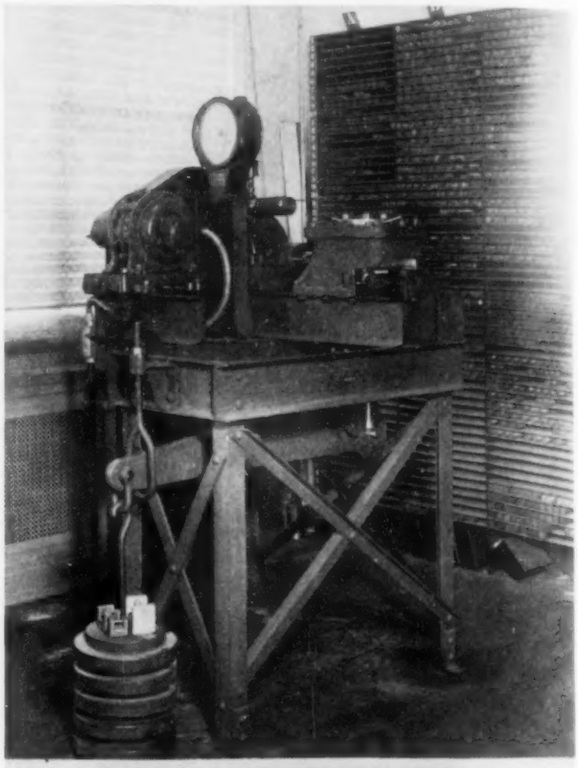
One of the most popular deposited surfacing materials that is being used for valve seats on steam service at elevated temperatures because it possesses many of the suitable characteristics is a cobalt-chromium-tungsten alloy. This material displays excellent resistance to wear, seizure and abrasion at high temperatures. This can be attributed to its unique property of "red-hardness" or, in other words, practically maintains its original cold hardness at elevated temperatures. It also withstands certain types of corrosion remarkably well and is fairly resistant to erosion.

DEPOSITING OF COBALT-CHROMIUM-TUNGSTEN MATERIAL

The usual practice, at least at the present, is to deposit this particular type of alloy manually by means of the oxyacetylene torch. This method of application produces smooth deposits and allows better control in preventing inter-alloying of the surfacing material with the base metal, which would otherwise lower the "red-hardness" with consequent reduction in galling and abrasion resistance. Figure 13 shows a group of welding operators surfacing both small and large valve parts. The smaller disks and seats are mounted in rotating jaws or chucks which can be revolved at will by the operators by means of foot controlled motor driven gear reducers. Preheating is a very necessary requisite if cracking of the surfacing material is to be avoided and on smaller parts this is usually accomplished by means of the oxyacetylene flame prior to deposition of the alloy. On some small and intermediate size parts having relatively heavy cross sections the preheating is generally done in gas fired furnaces, after which they are placed in the rotating machines for depositing. This results in more uniform temperatures and improved operating economies. In dealing with large parts, and also those made from certain types of alloy materials, which have peculiar cooling characteristics, it is necessary to maintain the preheating temperatures uniformly in specially constructed furnaces wherein it is possible to deposit the seating material simultaneously with preheating. This is illustrated by the two operators in the foreground of Fig. 13.

The procedure for surfacing with the oxyacetylene flame consists in bringing a small area of the preheated base metal to a sweating temperature. The end of the welding rod is then brought into the carburizing type of

Fig. 9—Wear Test Machine for Studying Seizure of Metals Under Heavy Loading and Temperature



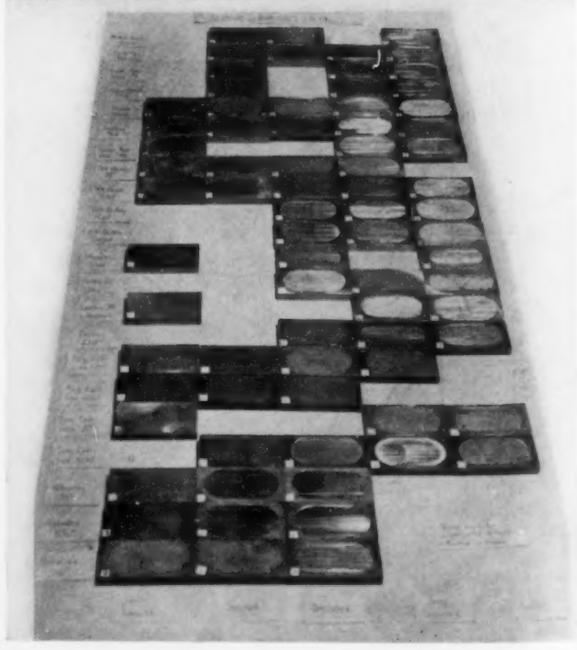


Fig. 10—Series of Metal Specimens That Have Been Subjected to Seizure Test

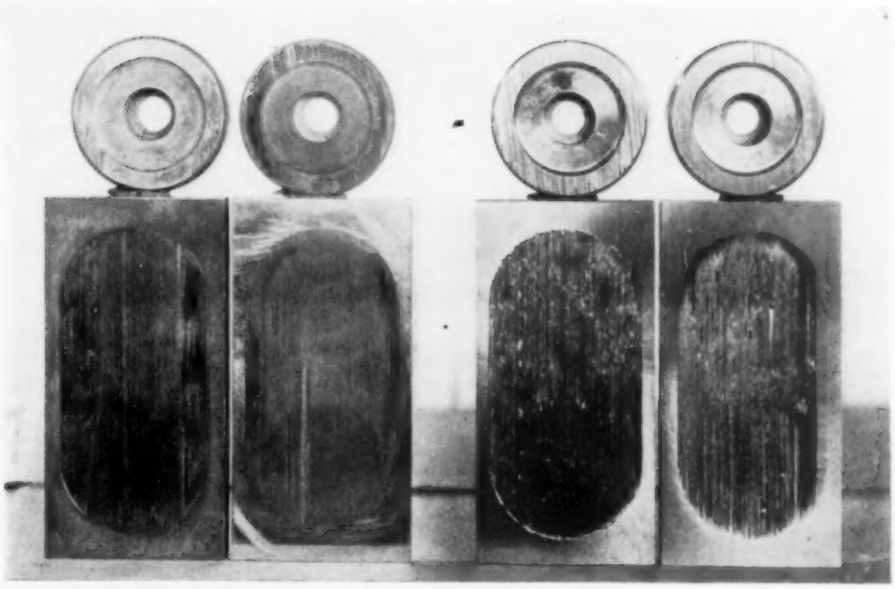


Fig. 11—Typical Seizure Test Specimens, Cobalt-Chromium-Tungsten Alloy at Left, and 12% Chromium Iron at Right

flame and allowed to melt and spread over the sweating surface. This operation is continued repeatedly by adding metal and the molten surface is spread by means of the welding flame. Our practice is to employ two or more passes as smoother deposits, free from blowholes, are thereby obtained and overheating of the base metal is minimized so that grain growth is consequently reduced, making it unnecessary to heat-treat after depositing with most of the simple alloy steels. The photomicrograph shown in Fig. 14 illustrates the sharp line of demarcation between the surfacing material and the base metal, indicating that practically no alloying between the two metals occurred. However, the fusion is very thorough and the bond between the two is exceptionally strong.

COOLING

The treatment after depositing also plays an important function in preventing cracking of the deposited material. Cracking is generally caused by differences in coefficients of expansion between the surfacing material and the base metal, this being particularly true in the case of the more simple steels. However, some of the alloy steels, upon being heated above the critical temperature when depositing surfacing materials, undergo allotropic transformations during the cooling period. This can be better visualized by making dilatometric studies upon the steels in question.

The heating and cooling curves plotted in Fig. 15 were obtained from specimens of carbon molybdenum and 4-6% chrome $^1/_2$% molybdenum alloy steels, which were heated and cooled in a dilatometer wherein the furnace containing the specimens was maintained in a helium atmosphere, thereby giving complete freedom from scale formation and decarburization. It will be noted that upon heating a point is reached at which the steel suddenly contracts and continues to contract over a

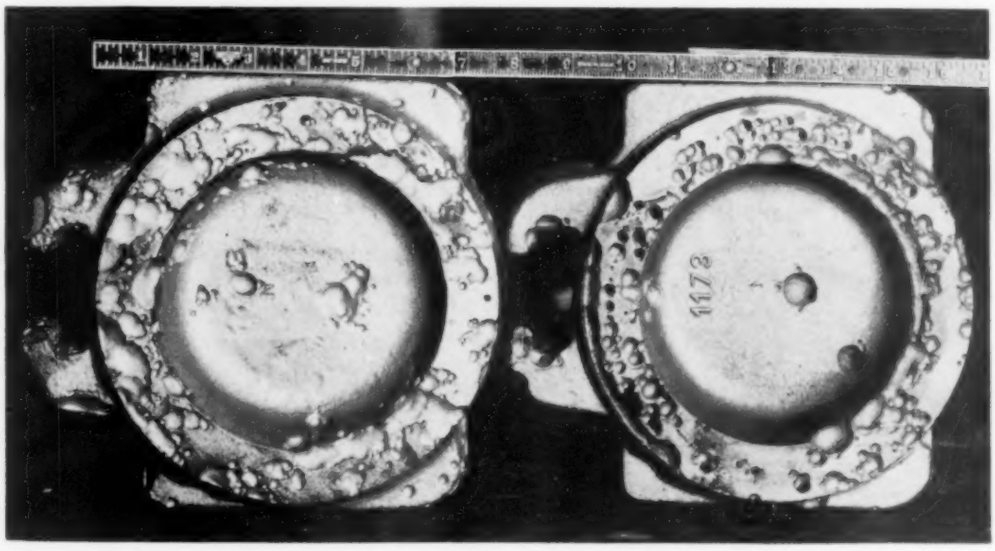


Fig. 12—Some Examples of Corroded Disks and Seating Surfaces

Fig. 13—Group of Welding Operators Depositing Surface Hardening Material on Valve Parts

considerable range of temperatures. Upon cooling a reverse effect is obtained, except that in most instances expansion, due to transformation, takes place in two steps at rather widely separated temperature ranges. In the case of carbon molybdenum steel the two transformations have merged so that the lower one commences before the upper one has gone to completion. The split transformations, on cooling, appear to be characteristic of alloy steels and is perhaps accounted for by the lack of homogeneity in their structures. The alloy rich and carbide rich portions of these structures tend to be sluggish in their response to transformation and the result is that the major effects occur at exceedingly low temperatures.

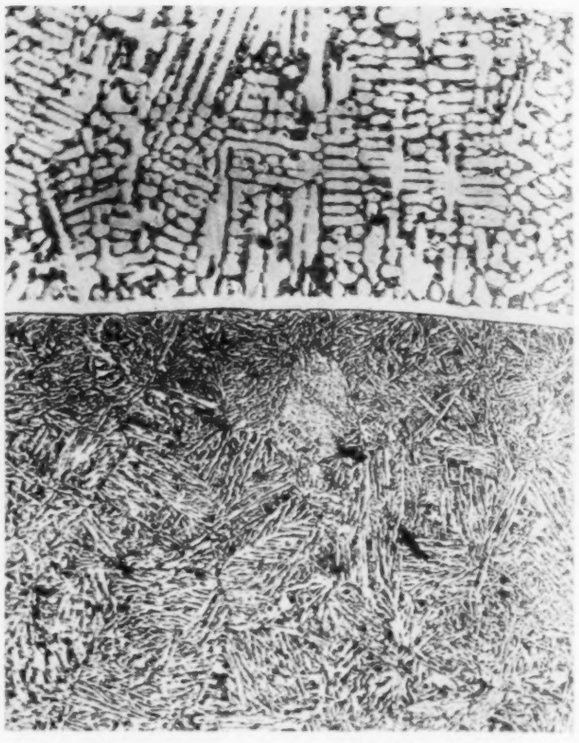


Fig. 14—Comparative Structures of No. 6 Stellite Cobalt-Chromium-Tungsten Deposit and Carbon Molybdenum Base Material Showing No Inter-Alloying Between the Two Metals

Fig. 15—Critical-Point Determinations Showing Depressed Transformation on Alloy Steel

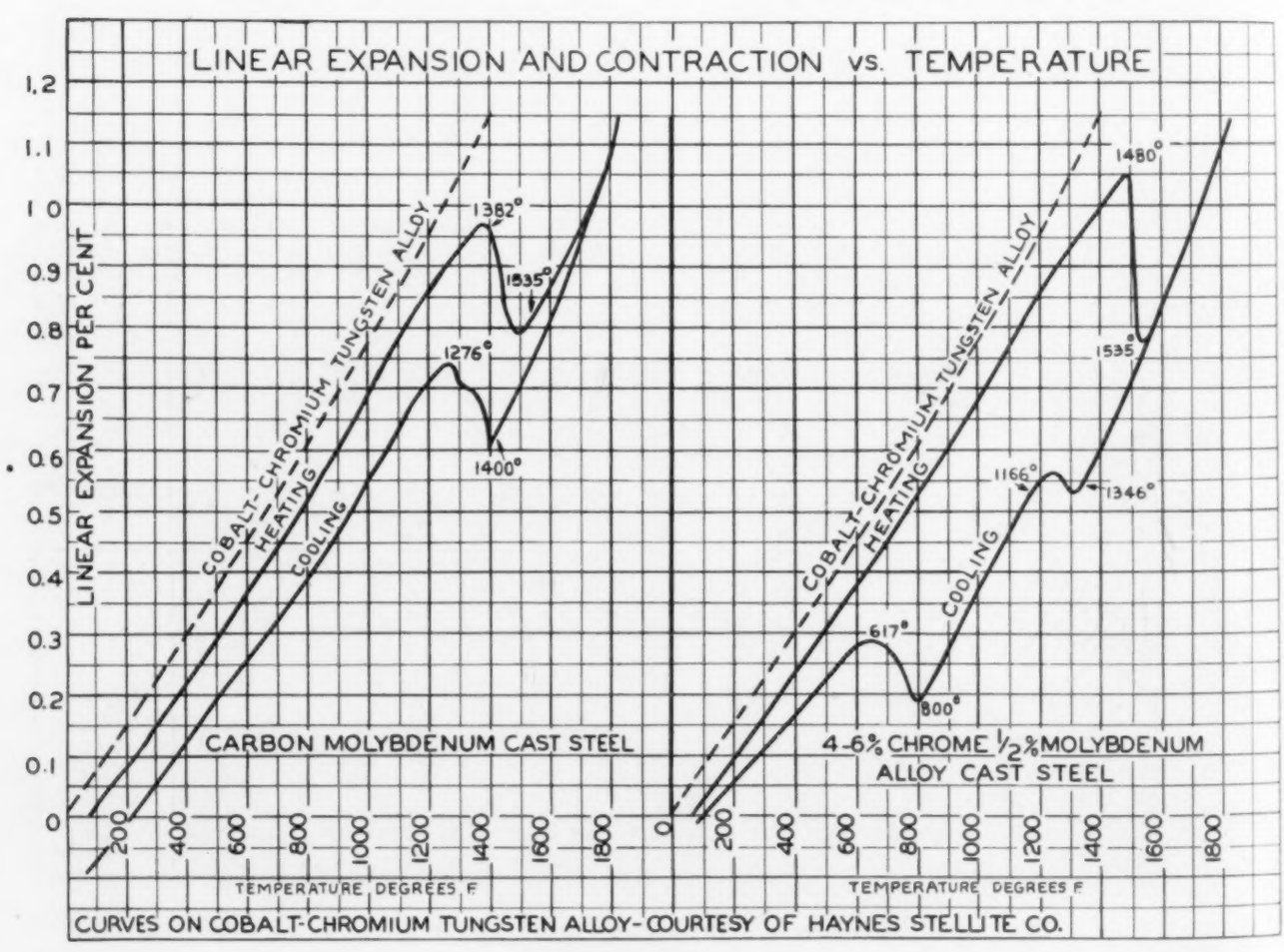


Fig. 16—Retarding the Cooling Rate of Surface Hardened Parts by Placing Them in Powdered Lime

It will also be observed from Fig. 15 that the cobalt-chromium-tungsten alloy, which is most widely used for valve seats, has no critical points or irregularities in the cooling curve. This phenomena gives definite indications why cracking of the surfacing material is so prevalent when dealing with certain types of alloy steel unless extreme precautions are taken in the cooling procedure.

It is considered good practice immediately upon completion of depositing the surface material to further heat the deposited and adjacent base metal, regardless of its analysis, to a uniform temperature and place the part in a container with powdered lime, as illustrated by Fig. 16. The thickness of the lime should be sufficient to give a very slow rate of cooling and our procedure is to cool from twelve to sixty hours, depending upon the size and shape of the structure.

After cooling, the parts are sand-blasted to remove all scale and present clean surfaces for the first inspection to note if any cracks are present. Minute checks or cracks are not always discernible until the surfaces have been machined or ground. If cracks are found it is then necessary to resurface completely by following the described procedure of preheating, surfacing and slow cooling, as localized heating will only cause further cracking.

MACHINING AND GRINDING

Parts to receive surfacing material are first machined to predetermined dimensions with proper tolerances and allowances for shrinkage so that the finished deposited metal is from $^1/_{16}$ inch to $^3/_{32}$ inch in thickness, depending upon the size and design. Deposits are generally applied twice as thick in order to prevent surface irregularities from interfering with the finished dimensions, which would otherwise necessitate resurfacing and add to the expense of the product.

The final finishing of the deposited metal is usually performed in several operations, depending upon the

Fig. 17—Stages of Preparation of Globe Valve Disks and Seat Rings. Reading Left to Right—After Surface Depositing, Rough Machining and Final Grind

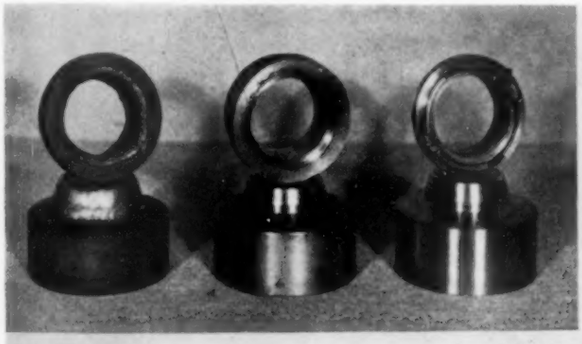


Fig. 18—Gate Valve Disks and Body Rings with Deposited Seat Surfaces. Disks Are Shown in Deposited and Final Finished State While the Rings Are Rough Machined and Finished

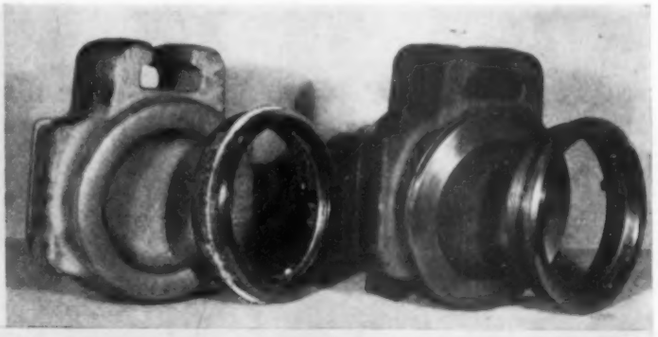


Fig. 19—Small, Intermediate and Large Globe Valve Disks and Seat Rings with Deposited Alloy Seats

Fig. 20—Checking Taper and Trueness of Deposited Seats on Gate Valve Disks

type of disk, body ring or valve body. Some are rough machined by means of tungsten carbide cutting tools, while others are rough ground prior to the finish grind. Figure 17 shows three sets of plug type disks with seat rings for a 2-inch high-pressure globe valve in their successive steps of preparation, namely, after surface depositing, rough machining and final machining of base metal with final grind of deposited seating material. In Fig. 18 virtually the same procedure is shown on gate valve disks and body rings of a larger size. Figure 19 pictures small, intermediate and large globe valve disks and seats in the finished state, showing slight variations in design.

After the various disks and rings are completed they are carefully examined and accurately checked for sizes and trueness by means of special gaging devices, one of which is illustrated in Fig. 20.

The parts are then assembled into valves and the contact bearing surfaces between the disks and rings are further checked by taking impressions with Prussian blue. If any slight irregularities exist they are removed by lapping to assure tightness on the hydrostatic and air pressure tests to which they are subjected before being stocked or sold to the consumer.

The application of deposited surfacing alloys of the cobalt-chromium-tungsten type to valve seats has vastly improved the reliability and operating life of valves in numerous installations where the service conditions are unusually severe, particularly in the modern high pressure, high temperature steam power plants.

The use of surfacing materials is constantly being extended, manifested by the fact that our company, aside from many others engaged in valve manufacture, produced in the last eight months of this year a total of 52,624 parts with surface alloy deposits. These consisted mainly of disks and seats which ranged in sizes from $^1/_4$ inch to 18 inches.

As pressures and temperatures increase it is safe to predict that further development of surface hardening materials will aid the valve manufacturer in coping with the serious problems that will be imposed on valve seats.

WELDING HANDBOOK

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33 West 39th St., New York, N. Y.

SETS OF BOUND VOLUMES OF JOURNAL

In order to provide some of the new members of the Society with an opportunity to complete their library on Current Welding Literature, the AMERICAN WELDING SOCIETY is offering to these new members an opportunity to purchase the last six bound volumes for the years 1932, 1933, 1934, 1935, 1936, 1937, at $25.00 a set. The price to non-members for individual volumes is $6.50 and for the set $30.00.

Each bound volume contains a Subject and Authors' Index and is bound in attractive imitation black leather covers. The set probably includes the most important welding information available in the literature.

Welding Society ACTIVITIES — Related Events

A MESSAGE FROM THE PRESIDENT

The Detroit Convention was decidedly a success. The registration was over 900, Foreign countries, Hawaii, and practically every state in the Union were represented. The local Committee on Arrangements cannot be too highly praised, and the Society Program, Convention, and Manufacturers' Committees, did splendid work. The technical papers were excellent, and the welding exhibits fine. The banquet was the optimum in such affairs. The meeting of Section Chairmen was productive of good feeling and understanding. As a direct result the objectionable retroactive feature of the by-laws governing refunds to sections was repealed at the first meeting of the new Board of Directors. President Lang was regrettably absent because of illness, but Colonel Jenks ably officiated for him, and presented his report, which revealed the fruition of some of his constructive planning. Altogether the Convention augured well for the future of the Society.

A future of increasing service is assured if the Society keeps ever in mind its true destiny as the interpreter and voice of welding, which today is probably the greatest single factor in our complex industrial life. The Constitution expresses the purposes of the Society in these simple and concise words:

"The objects of the Society are:

(*a*) To advance the science and art of welding.

(*b*) To afford its members opportunities for the interchange of ideas with respect to the science and art of welding, and for the publication of information thereon.

(*c*) To conduct research into the science and art of welding, cooperating with other societies, associations and governmental departments for the benefit of the industry in general.

(*d*) To acquire and dispose of property for the purposes aforesaid.

(*e*) To do all other things incidental or conducive to the attainment of the above-named objects, or of any of them."

It is well to frequently remind ourselves of these aims for, in the bustle and hustle of our busy, and often selfish, lives, they are easily forgotten, or assigned to secondary places. They provide the unity of purpose and effort which are needed for continuity from one administration to the next. Presidents come and go, but the Society lives on.

Mr. Gibson and Mr. Lang, in spite of troubled reigns, laid a foundation upon which it is quite safe to build. Both dreamed and planned and worked for a growing and aggressive, and truly technical Society. They greatly increased the membership and improved the technical organization. We should carry on where they left off, ever seeking to strengthen the Society in membership, in technical achievement, and in financial stability; to build up a financial reserve if possible; to invite, receive, digest, codify, and disseminate information, always sensitive and responsive, but never subservient to the demands of industrial groups; to actively promote and direct fundamental research through the Welding Research Committee, by colleges, individuals and industrial organizations; to encourage welding education in schools and through all available mediums; to make the world welding conscious; to assist the sections in the formulation and conduct of coordinated, well balanced technical programs, and, in general, to do everything reasonably possible to increase the knowledge and use of welding by all processes.

The Society By-Laws and organization are now well adapted for the attainment of these desirable ends. Each of the five geographical districts has an Executive Committee consisting of the District Vice-President, the District Secretary, and the Chairmen and Secretaries of the Sections in the District. All District Vice-Presidents are members of the Board of Directors. These District Executive Committees are expected to do much to direct, coordinate, and integrate the activities within their respective districts, and, through the Board of Directors and Society Headquarters, to bring about a coordination and knowledge of all district affairs.

Perhaps something special should be planned in celebration of the 20th anniversary of the founding of the Society which occurs March 27th. Suggestions are invited.

The Committee on Outline of Work, which came into being under Mr. Lang, and which has functioned for a few months only, will greatly strengthen the technical work of the Society. This Committee, of which Colonel Jenks is the new chairman, decides when new technical committees are needed, and recommends their personnel; determines when a committee has completed its work, and when its work should be expanded; decides questions of jurisdiction between various committees, and tries to prevent overlapping of their activities with each other, and with committees outside the Society; correlates and controls the standardization work of the technical committees in the development of codes and regulations; and recommends the appointment of Society representatives in the development of codes, standards, etc., by outside groups. A primary purpose of this Committee is to see that good codes, only, are prepared and kept up-to-date, and, that these codes are the fewest and simplest consistent with the needs of industry.

To the Headquarters staff should be added a technical secretary to relieve Mr. Spraragen of his work with technical committees, and enable him to devote his entire time to the Journal, which he so ably edits, and to the work of the Welding Research Committee. The Society will be kept informed of developments along this line.

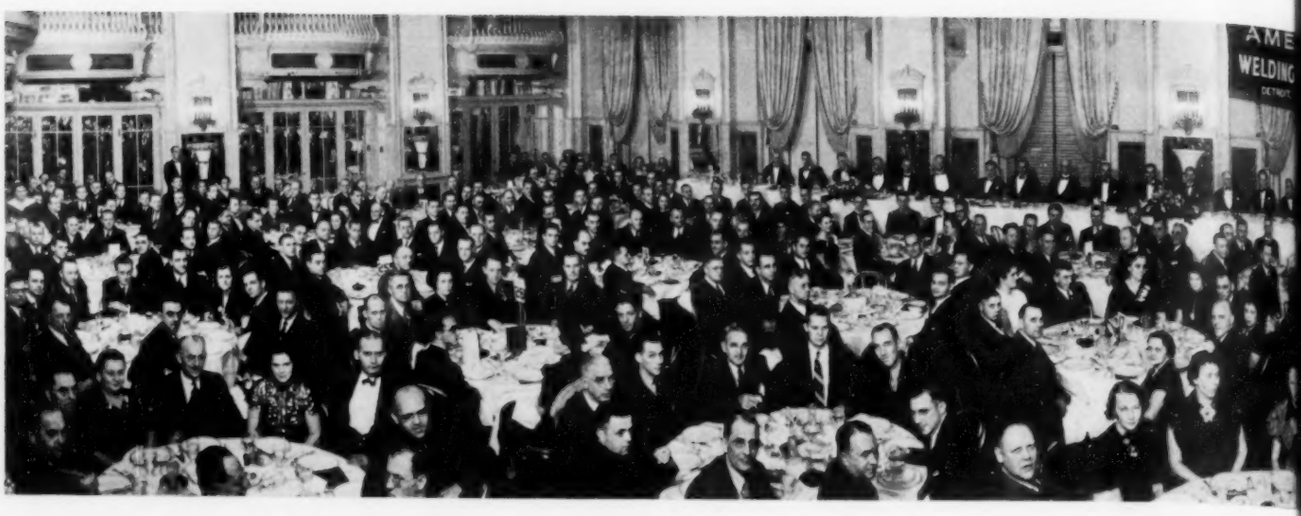
The new Directors represent the entire country from coast to coast, and Great Lakes to Gulf; the personnel of the new Executive Committee is also as widely scattered geographically as regular attendance at the meetings will permit; the technical committees represent more land area than ever before; and the President expects to travel widely, with open eyes and listening ears. With this set-up, combined with good feeling and united effort, the Society will advance.

H. C. BOARDMAN,
President

ANNUAL MEETING

The AMERICAN WELDING SOCIETY has just concluded the greatest Annual Meeting in its history. There were record breaking attendances at the technical sessions (over a thousand), at the social functions (Annual Dinner 500) and at the Metals Exposition (50,000).

The meeting opened with a President's Reception on Sunday afternoon, which was well attended and was a forerunner of the attendance to be expected at the other events. Forty-six technical papers were presented which represent a cross section of modern welding developments and research during the past year. Practically all of the major branches of industry were covered in these technical papers and in the discussion which followed. Although simultaneous sessions were under way practically all the time there was no confusion. In the Journal and in preprint form 37 of the 46 papers were printed in advance of the meeting and available for study by those interested. Other papers will be printed in the November and January issues of THE WELDING JOURNAL.



American Welding

Practically every state of the union was represented in the registration, including far off California and Washington and the most distant Section, Hawaii. Of course, the prize for distance must go to some of our foreign friends who took occasion to be present, including representatives of Australia and England. The meeting was formally launched on Monday morning by an address of welcome by Mayor Reading of the City of Detroit. The Mayor's address was followed by the presentation of medals and prizes by the Board of Awards.

The Samuel Wylie Miller Memorial Medal was awarded to Mr. J. W. Meadowcroft, Assistant Works Manager of the Edward G. Budd Manufacturing Company, for his pioneering work in the fabrication by welding of automobile bodies.

The Lincoln Gold Medal for the year 1938 was awarded to James C. Hodge and Cornelius R. Sadler for their paper on "Weldability and Properties of Materials for Casing Strings."

The Industry and Welding prize for the best thesis on Gas Welding was awarded to G. R. Maples, Jr.

In addition to the technical sessions there were quite a number of committee meetings and research conferences, also, a round table discussion on qualification of processes and operators. A successful meeting of the representatives of various Sections was held on Wednesday afternoon.

The outstanding social feature was the Annual Banquet and Dance held by the Society on Thursday evening. The Grand Ballroom of the Book Cadillac was filled to capacity and it was necessary to arrange for quite a few tables in the balcony. A good dinner was served. Outstanding features were the remarks of the Toastmaster Harvey Campbell, a talk by Mayor Reading and the keynote speech by W. J. Cameron of the Ford Motor Company. Mr. Cameron in his clear forceful fashion gave a true picture of the business situation and how it may be improved.

An inspection trip was arranged on Friday afternoon to the Ford Motor Company. Quite a few of the members stayed over and participated in this interesting and instructive trip. Members saw firsthand the important part welding plays in the manufacture of the modern automobile.

There was one note of regret throughout the entire meeting, namely, the forced absence of President Lang due to illness. Resolutions of sympathy and congratulations for successful work accomplished were passed at the Opening Session, the Executive Committee meeting, the Business session and the Board of Directors meeting.

The annual Business Session was held late Friday morning, at which Colonel G. F. Jenks, Senior Vice-President of the Society, presided. The Annual Report of the President was read and supplemented by reports of a number of the Committee Chairmen present. This report is reproduced elsewhere in this Journal.

Summarizing the report, the progress made by the AMERICAN WELDING SOCIETY during the past year might be told in the following headlines: Welding Society publishes a 1200-page Handbook; Membership of the Society increases by more than 39% to a total of 3538; Welding Society spends $30,000 on a national coordinated program of research; First District meeting AMERICAN WELDING SOCIETY held in Los Angeles, California; forty-six technical papers to be presented at Annual Meeting Welding Society; Committee on Outline of Work coordinates Society activities. On the other hand, these headlines would not tell the complete story unless some subtitles were permitted as follows: Change in By-Laws designed to make the Society a strong technical organization and to increase its efficiency and effectiveness; The AMERICAN WELDING SOCIETY issues codes on—Inspection Methods; Welding of Piping in Marine Construction; Welding of Oil Storage Tanks; Society issues revised rules on Welding in Building Construction; Welding of Gravity Tanks, Tank Risers and Towers, and Standard Qualification Procedure.

The tellers Committee announced the election of the following Officers:

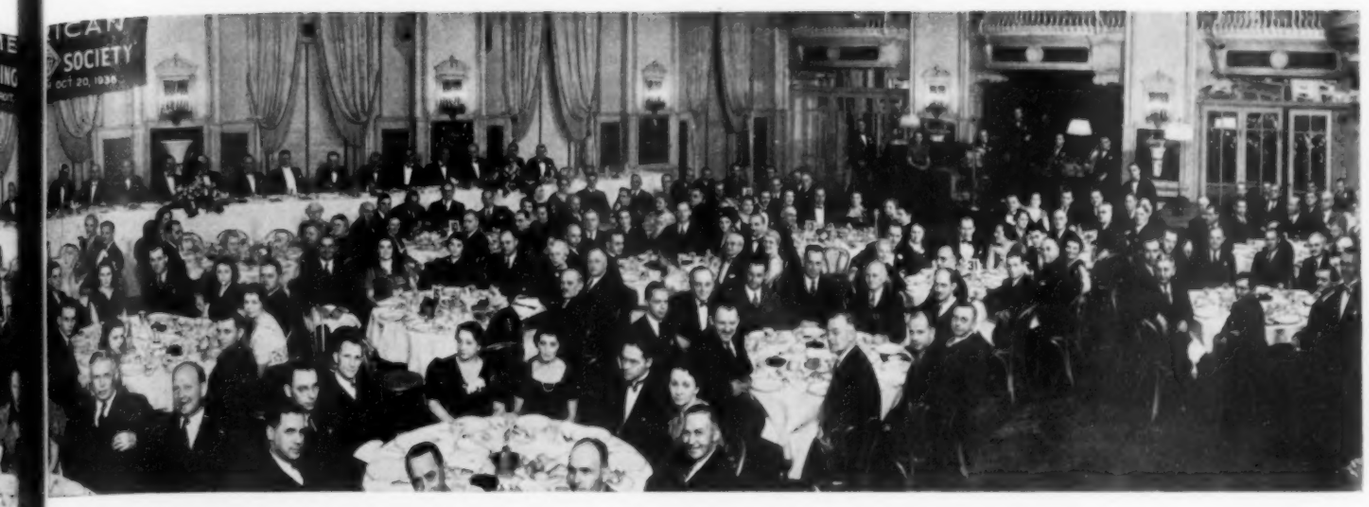
President—H. C. Boardman, Chicago Bridge and Iron Co.
1st Vice-President—Col. G. F. Jenks, Ord. Dept., U. S. Army
2nd Vice-President—Turner C. Smith General Petroleum Corp.
District Vice-Presidents
New York-New England—Wendell F. Hess, Rensselaer Polytechnic Institute
Middle Eastern—W. W. Petry, The Cincinnati Milling Machine Co.
Middle Western—K. L. Hansen, Harnischfeger Corporation.
Treasurer—C. A. McCune, Magnaflux Corporation
Directors-at-Large:
C. A. Adams, Consulting Engineer, Edward G. Budd Mfg. Co.
Marvin Cook, Humble Oil & Refining Company
F. T. Llewellyn, U. S. Steel Corporation of Delaware
C. E. Woodman, Kansas City Bridge Company

The first meeting of the newly elected Board of Directors was held as a luncheon meeting on Friday afternoon. This occasion formally closed the Nineteenth Annual Meeting of the AMERICAN WELDING SOCIETY.

Great credit is due for the unusual success of this meeting to a large number of people, including the numerous local committees of the Detroit Section, the Convention Committee and the National Program Committee. The sessions, particularly, the social features were livened and made more pleasant by the presence of a large number of ladies. A special program was provided for their entertainment for which credit is due again to the local committees of the Detroit Section.

POWER EXHIBIT

The Thirteenth National Exposition of Power and Mechanical Engineering will be held at the Grand Central Palace, New York, during the week of December 5 to 10, 1938. Over 260 manufacturers have already engaged space.



Society Annual Banquet

OUR NEW PRESIDENT

At one time the enthusiasm of our new President for welding was of such nature as to seriously jeopardize his well-being at the hands of his associates. Fortunately, however, these same associates acquired sufficient enthusiasm to desist from these threats of violence. Harry Clow Boardman was born in Plainfield, Illinois in 1887. He graduated from the University of Illinois with the Bachelor of Science Degree in 1910 and entered the employ of the Chicago Bridge & Iron Company as Draftsman; he later became Chief Draftsman and Designing Engineer. In 1916 he become a Corporal in the First Illinois Field Artillery, later, Second Lieutenant and Captain. During the latter part of 1917 he became Commander of Battery "E," 332nd Field Artillery, 86th Division. He became Instructor in the Field Artillery in 1918 and in October of that year received the rank of Major. From 1919 to 1922 he was engaged in automobile tire and accessories business in Kansas City, Mo. In 1922 he entered the employ of the International Filter Company where he held position as Designer and later Superintendent of Construction. In 1924 he become Instructor in the College of Engineering, University of Illinois, and in 1926 received a C.E. Degree from the University. In the same year he returned to the Chicago Bridge and Iron Company as Research Engineer, a position which he has occupied to date. His real title is Director of Research, but he modestly assigns this position to his chief, Mr. George Horton and feels that he is more properly labeled Research Engineer under Mr. Horton. His work has been mostly of a structural or mathematical nature or with particular reference to welding. He is author of a number of technical articles dealing with storage tanks, pipe lines, mathematics and hydraulics. He is co-author of "Mathematical Tables for Use in Computing Arcs, Chords and Versines." He holds membership in the following societies: Tau Beta Phi; Sigma Xi; Fellow-American Assn. for the Advancement of Science; American Society of Civil Engineers; Western Society of Civil Engineers; AMERICAN WELDING SOCIETY (Ex-Chairman Chicago Section); American Society for Metals; A.S.M.E. Boiler Code Committee and American Petroleum Institute.

H. C. Boardman

Our President is well known to our members through his writings, his presentation of papers and his service on many committees. The Society is indeed fortunate to be able to enlist the interest of a man of the standing and caliber of Mr. H. C. Boardman.

OUR SENIOR VICE-PRESIDENT

Colonel Glenn F. Jenks, Chief of Technical Staff, Ordnance Department, U. S. Army, Washington, D. C., was reelected Senior Vice-President of the AMERICAN WELDING SOCIETY. Colonel Jenks served as Acting President throughout the Annual Meeting of the A.W.S. in Detroit due to the illness of President Lang. A vote of appreciation was extended to Colonel Jenks by the membership for the very able way in which he served in this capacity during the meeting.

Col. G. F. Jenks

Colonel Jenks was born at Deansboro, N. Y., June 13, 1880. Graduate of Hamilton College (Clinton, N. Y.) B.S. 1901, M.S. 1904. Graduate of Army War College (1924) and of Harvard Business School (M.B.A. 1930). Entered the Army as a 2nd Lieutenant, Artillery Corps, 1901, and detailed in the Ordnance Department, 1903. During the World War served as Colonel, National Army, at Headquarters A. E. F., and at Headquarters Service of Supplies A. E. F. in charge of technical work in heavy artillery in the Office of the Chief Ordnance Officer, and for two months prior to the Armistice as Chief Ordnance Inspector of Artillery at Headquarters First Army. Was decorated by the French Government as Officer of the Legion of Honor and was awarded the Distinguished Service Medal by the American Government.

Since the war served in the Office of the Chief of Ordnance in charge of engineering and production of artillery material, and later in the 8th Corps Area as Chief

Ordnance Officer. Was at Watertown Arsenal as Director of Research for two years and then in command from 1932 until 1937, when assigned as Chief of the Technical Staff in the Office of the Chief of Ordnance, U. S. Army. Promoted to the grade of Colonel, Ordnance Department, November 1, 1933.

Member of the A. W. S., A. S. M. E., A. I. M. E., A. S. M., A. S. T. M. and S. A. E. Member of the Engineering Foundation Welding Research Committee and Chairman of the Industrial Research Division of that Committee.

OUR SECOND VICE-PRESIDENT

Turner C. Smith of General Petroleum Corporation, Los Angeles, Calif. is Structural Engineer in the general engineering staff of the General Petroleum Corporation, and is chairman of its engineering committee on oil storage tanks. He is also a member of its committees on unfired pressure vessels and valves for oil field, pipe line and refinery services.

He has been an active member of the AMERICAN WELDING SOCIETY for more than a decade, and has served as chairman of the Los Angeles Section, and as vice-president of the Pacific Coast Division. He is also a member of the A. S. A., the Pacific Coast Building Officials' Conference and the Structural Engineers' Association of Southern California.

Following his graduation from the University of Arizona he received a commission in the United States Army, went to France with the 21st Engineers and had charge of a railway machine shop at Abainville in 1917–18.

OUR DISTRICT VICE-PRESIDENTS

New York and New England—Wendell F. Hess

Dr. Wendell F. Hess is Associate Professor and Head of the Welding Laboratory, Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, N. Y. Dr. Hess is a member of the AMERICAN WELDING SOCIETY, the Society for Promotion of Engineering Education, of Sigma Xi, of the American Institute of Electrical Engineers and of the American Association for the Advance of Science. Dr. Hess is a graduate of R.P.I., from which he also received his Doctor's Degree in 1928. He has been connected with R.P.I. as Instructor, Assistant Professor of Electrical Engineering, and more recently as Assistant Professor of Metallurgy. He is Chairman of the Northern New York Section. Dr. Hess is well-known to the members of the Society having published a number of articles in the Journal and having attended eight consecutive Annual Meetings of the Society.

Middle Eastern—W. W. Petry

W. W. Petry of The Cincinnati Milling Machine Co., Cincinnati, Ohio was born January 24, 1894, at Port Washington, Ohio. He is a product of the cooperative engineering college of the University of Cincinnati.

He was maintenance engineer at the American Rolling Mill Company serving that company for 12 years during which time he had much to do with developing welding.

In 1926 in search for a broader field in welding, he started a welding consulting practice, which quickly developed to a large welding fabrication business, the United Welding Company. His duties as consultant also expanded to cover the central and eastern states. At present he is devoting his entire time to the development of welded machine structures and plant maintenance at the Cincinnati Milling Machine Company.

Middle Western—K. L. Hansen

K. L. Hansen, of the Harnischfeger Corporation, Milwaukee, Wisconsin was born in Norway. He came to the United States in 1901. For $2^1/_2$ years he worked in various shops in Chicago, most of the time for the Western Electric Company, assembling fan motors and arc lamps. In the fall of 1903 he entered the University of Illinois. From the summer of 1905 until early in 1906 he worked for the Chicago Edison Company in various capacities. In February 1906, he joined the Westinghouse Electric & Mfg. Co. and worked for four years in several positions. In the fall of 1919 he went to work for the Louis Allis Company (then the Mechanical Appliance Company) of Milwaukee. In this Company he was designing engineer for a.-c. and d.-c. motors and generators, later becoming Chief Engineer. When he severed connections with this Company he entered upon consulting and development work of his own. The Hansen Arc Welder, first built and marketed by the Northwestern Manufacturing Company of Milwaukee, was invented and designed by him. In the early part of 1932 the Harnischfeger Corporation of Milwaukee took over the Northwestern Mfg. Company and has since manufactured and marketed the Hansen Arc Welder. He has since that time been acting in a consulting capacity for that Corporation on problems pertaining to welding and welding equipment.

He has written many papers and articles on theory and design of electrical machinery and some on arc welding generators. He has served in the following capacities: Chairman of Committee on Electric Welding of A.I.E.E., Chairman of the Milwaukee Section of A.I.E.E., Chairman of the Milwaukee Section of the AMERICAN WELDING SOCIETY.

OUR TREASURER

Charlie McCune is well known to all of us and to the welding industry. He was one of the founders of the Society and in 1922 was elected President. He was appointed Treasurer of the Society in 1923 and reappointed each succeeding year. This year Charlie was *elected* Treasurer for a three-year term.

Mr. McCune was born in Jersey City, N. J. in 1879. He received his education in general science at Cooper Union, New York, N. Y.

From position of Chief Draftsman of Safety Car Heating and Lighting Company, in 1904 he became Assistant Engineer, and later Chief Engineer of Commercial Acetylene Company, retaining this position until 1916 when he became Sales Engineer of the Page Steel and Wire Company. In 1924 he was appointed Director of Research of the American Chain Company and, after holding this position for six years, he resigned in 1930 to become Director of Research of the Welding Engineering and Research Corporation. Following the dissolution of this Corporation, he assumed his present position as Director and Secretary of the Magnaflux Corporation in New York.

From 1919 to 1937 he served as Chairman of the Filler Metal Specifications Committee. He is author of numerous papers on acetylene and its uses, the metallurgy of welding rods and welds, the manufacture of iron and steel wire and research methods in iron and steel production. He is a member of the A.S.M.E., A.S.T.M., A.S.M., past-president and member International Acetylene Association and a member of the Advisory Board of the National Bureau of Standards.

OUR DIRECTORS-AT-LARGE

C. A. Adams, Consulting Engineer,
The Edward G. Budd Manufacturing Co.
Philadelphia, Pa.

Born in Cleveland, Ohio, in 1868. Educated in the Case School of Applied Science. B.S. 1890 E.E. (Hon.) 1905, D. Eng. (Hon.) 1925. Lab. Asst. Case School 1886–90, Engr. Brown Hoisting and Conveying Machine Co. Sept.–Dec. 1890. Instructor Elec. Engr. Harvard University 1891–96, Asst. Prof. 1896–1906, Prof. E. E. 1906–11, Lawrence Prof. of Engrg., since 1911, Dean Harvard Engrg. School 1919 when he resigned to accept membership on National Council of Defense; served as Chairman Welding Committee, Emergency Fleet Corporation, U.S.S.B.; appointed Chairman, Division of Engineering, National Research Council. He returned to Harvard in 1921 as Prof. Engrg., Prof. Emeritus from 1936. Consulting Engineer, E. G. Budd Mfg. Company, Babcock-Wilcox Company and other companies. Author of many papers. He was Founder, 1st President and is an Honorary member of the AMERICAN WELDING SOCIETY. Director American Bureau of Welding from organization to dissolution of Bureau when he became Chairman, Engineering Foundation Welding Research Committee. Member, Welding Handbook Editorial Committee, served as President of the A.I.E.E., member I.E.E. (London), V.D.E. (Berlin), S.P.E.E., A.S.M.E., A.S.C.E. and A.S.T.M.

Marvin Cook,
Humble Oil & Refining Company,
Houston, Texas

Born at St. Joseph, Mo., Sept. 16, 1899. Primary education—Southern Kansas Public schools; started oil field work in 1916 after finishing High School; U.S. Navy 25 months during World War; Combination rotary-cable tool driller from 1919–26 in Kansas, Oklahoma, Texas, New Mexico, Mexico, Wyoming and Montana. University of Kansas 1926–30, finished B.S. in Chemical Engineering (Metallurgical Option). Production Dept. of Humble Oil & Refining Co. 1930–38 giving special attention to

problems in welding, repair, maintenance of material and equipment and to investigation of selection of materials and equipment. Member: Scottish Rite; A.P.I. Pipe Committee; A.S.M. Chairman, South Texas Section, AWS; and Registered Professional Engineer of State of Texas.

F. T. Llewellyn,
U.S. Steel Corporation of Delaware,
436 7th Avenue,
Pittsburgh, Pa.

Born in Cardiff, Wales in 1869. He taught school and attended the University of London from 1886 to 1889 and came to this country late in 1890. His first position was in the structural steel department of the Gillett-Herzog Mfg. Co., Minneapolis. Four years later he was appointed southern engineer of the same firm and was located at New Orleans in charge of construction. He supervised the first steel skeleton tier building in New Orleans and the first steel frame building in Louisiana. In 1900 he had charge of the construction of the first steel frame building in Mexico City. While abroad, his company was absorbed by the American Bridge Company. In 1902 he became contracting manager at St. Louis and later in New York. From 1906 to 1917 he was engineer in the New York office of the Carnegie Steel Company and devoted his attention to the development of new products. In 1917 he was loaned to the Emergency Fleet Corporation and devoted his attention to the simplification of steel requirements for ships, and in allotting steel to shipyards. From 1919 he has been attached to the President's office of the U. S. Steel Corporation and has concerned himself with the development of new products, especially in the structural field. He was President of AWS from 1928 to 1930, and for a number of years has served on the Executive Committee and Board of Directors. He is a member of the Structural Steel Welding Committee, Engineering Foundation Welding Research Committee and Welding Handbook Editorial Committee. He is a member of numerous organizations, among which are included: A.W.S., A.S.C.E., A.S.T.M., A.S.M., A.S.N.A. and M.E.

C. E. Woodman,
Kansas City Bridge Company,
215 Pershing Road,
Kansas City, Mo.

Born in Miami County, Kansas. Completed education in the spring of 1917. Voluntarily enlisted in the United States Army; experienced eighteen months of active service overseas in the World War; received Honorable Discharge in 1919. Has had ten years experience in the Petroleum Industry in Laboratory, Refining and Compounding Departments, also Sales Lubricating, Engineer; ten years Director of purchases and assisting with maintenance of equipment for the Kansas City Bridge Company. Helped organize the Kansas City Section of the AWS in 1937 and was its first Chairman. President of the Board of Education of Shawnee-Mission Rural High School, Johnson County, Kansas.

OBITUARY

T. F. Barton, fifth President of the American Welding Society and superintendent motive power of the Chesapeake & Ohio, with headquarters at Richmond, Va., died on October 14th. Mr. Barton was born in London, England, on March 21, 1867, and began his railroad career in 1887 with the Grand Trunk. He remained in the employ of that road for six years, serving successively as machinist apprentice, locomotive fireman and journeyman. During the 10 years he served with the Illinois Central he held the positions of machinist, gang foreman, roundhouse foreman, general foreman, master mechanic and superintendent shops. Prior to his connection with the Chesapeake & Ohio he was in the employ of the Delaware, Lackawanna & Western for a period of 15 years, serving in the capacity of master mechanic at Kingsland, N. J., when he accepted the position of master mechanic of the C. & O. He was appointed general master mechanic of the Western General division at Huntington, W. Va., on February 1, 1924, which position he held until May 1930, when he was promoted to superintendent motive power at Richmond.

Mr. James A. Savage, Sustaining Member of the American Welding Society, representing the S. Morgan Smith Company, died in Boston on September 30th, after an illness of several months.

The Company is now represented in its Sustaining Membership by Mr. Walter E. Hollingshead.

1939 CONVENTION AMERICAN FOUNDRYMEN'S ASSOCIATION

Cincinnati has been selected as the place of the 1939 annual convention of the American Foundrymen's Association, with the meeting opening Monday, May 15th and continuing through Thursday, May 18th.

The 1939 convention will be held without an exhibit and patterned after the successful technical meetings held in Chicago at the Edgewater Beach Hotel in 1927, and at the Royal York Hotel in Toronto in 1935. The entire program will be devoted to technical, management and general interest sessions, shop operation courses, round table discussions and committee meetings, plant visitation and social functions that add to the enjoyment of annual Foundrymen's Week.

VETERAN FIRM ISSUES REVISED STEEL HANDBOOK

The Philadelphia firm of Horace T. Potts Company, Warehouse Distributors of Steel and Supplies, recently issued the 21st Edition of their Steel Handbook. Considerable space is devoted to welding accessories, especially shielded-arc type electrodes so rapidly being adopted by industry. This publication contains a wealth of technical data relating to forms and types of steels and the uses to which they may be applied.

WATERTIGHT STEEL HOUSE "SAILS" ACROSS RIVER TO PERMANENT HOME SITE

Launched at Peoria, Illinois, recently and towed across the Illinois River on its own bottom was the first residence ever to "sail" to its destination.

A 32 ft. x 44 ft. watertight arc-welded steel house, (See Cover), fully equipped with furnace, stoker, cooling system, laundry, plumbing—even partially furnished—was dropped "overboard" by a crane (See Fig. 1), from the yard of the R. G. LeTourneau factory and towed across the river by a tug (See Fig. 2), to be placed on its permanent site on the Le Tourneau experimental farm.

Fig. 1. The Arc-Welded Steel House After Launching by Crane Into the Illinois River

Fig. 2. Shades of Noah and the Ark! The Modern All-Steel, Arc-Welded House Afloat on the Illinois River in Tow of a Motor Boat

The house is constructed of solid steel completely arc welded into a watertight, weather-resisting, fire-, dust-, termite-proof dwelling. For the voyage across the river the doors of the house were sealed to a height of 28 inches by means of steel plates and rubber gaskets. The house "drew" approximately 1 foot. After the maiden voyage, inspection showed an absolutely dry interior.

This "sea-going" house was built complete within the LeTourneau factory. Its construction utilizes arc-welded steel panels, which comprise both walls and wall frame. The panels, which are pressed in a die to a form which enhances appearance and adds rigidity, consist of two 12-gage sheets spaced approximately 5 inches apart for walls and 10 inches for roof, joined together by small braces as shown in Fig. 3. The space between the inner and outer plates is for insulating material which is blown into the panels at various intervals during erection.

The steel house was proposed and outlined by R. G. LeTourneau, president of the company, and designed by an architect for providing employees with

Fig. 3. Twelve-Gage Sheets Arc Welded to Stampings Form the Panels

complete, convenient and attractive homes that could be rented or sold at moderate cost. The design embodies the latest, most modern trends in architecture .... utilizing every foot of space and providing attractive rooms of generous size. In addition, these all-steel panel buildings have proved ideal as offices, filling stations and garages.

SPECIAL COURSE IN WELDING ENGINEERING FOR MEN IN INDUSTRY

The establishment of the new Welding Laboratory in Rensselaer Polytechnic Institute offers an unusual opportunity for pursuing studies in the field of welding. With a view to making these facilities available, an intensive course has been planned for engineers who are qualified to take advantage of them.

General Information

The intensive course will be of four weeks duration, with the option of an additional two weeks of experimental work of special interest to the individual student. Time will be devoted to metallurgy theory, theory of welding and structural design. Laboratory experience will include heat treatment, microscopic examination, welding, cutting and physical, magnetographic and radiographic testing. There will be regular library assignments, discussion groups and visits to nearby plants. The optional two weeks will be available for more laboratory experience in particular branches such as the weldability of a certain type of steel, spot welding, or any other phase which may have a special appeal.

Eligibility

The course is open to graduates who have completed courses leading to degrees in engineering or allied sciences in recognized universities or schools of engineering. It is also available to men whose responsibilities in industry have given them an experience equivalent to an engineering course. Each applicant must submit a record of his training and experience with references from men who are familiar with his work.

Admission to the course in welding engineering is subject to the final approval of the Committee on Graduate Study of the Rensselaer Polytechnic Institute.

Schedule of Courses

The schedule for the basic course of four weeks duration will be as follows:

	First Week	Second Week	Third Week	Fourth Week
A	Metallurgy Theory	Welding Theory	Welding Theory	Welding Theory
B	Welding Theory	Welding Laboratory	Welding Laboratory	Welding Laboratory
C	Structural Design	Structural Design	Metallurgy Laboratory	Weld Testing
D	Library assignments alternating with discussion groups.			

Content of Courses

Metallurgy Theory.—The properties of metals; the effect of alloy additions; the meaning and use of alloy diagrams; the changes in properties and structure, grain coarsening and grain refinement resulting from the heating and cooling of metals; precipitation hardening.

Welding Theory.—Arc welding, gas welding, resistance welding, thermit welding, atomic hydrogen welding, flame and arc cutting, a review of the processes and equipment used. Progress in the development of welding. Factors affecting the weldability of metals: the nature of the metal, the nature of the process, the nature of the structure. Special techniques for particular conditions: procedure control, peening, preheating, concurrent heating, stress relieving. Principal spheres of usefulness of various welding processes. Factors involved in the cost of welding. Allied processes: surfacing, brazing, spray coating, flame hardening and softening. Welding as a tool of manufacture and construction. Application of welding to machine design. Comparative advantages of alternative methods. Mass production. Automatic welding. Electrical control, design and power requirements. Strength of welds for design purposes. The evaluation of welds: testing methods; tensile, bend, fatigue, impact, radiographic, micrographic, magnetographic, miscellaneous. Inspection of welding, qualification of welders. Codes and specifications. Standardization. Symbols.

Structural Design.—Design and detailed drawings of typical members and connections in steel buildings, roof trusses and bridge trusses. Comparison with riveted structures.

Metallurgy Laboratory.—Change of properties and structure resulting from heating and cooling metals; the examination of fractures, microscopic examination of metal structures and the structure of welds; radiographic examination.

Welding Laboratory.—Experience in the operation of arc, gas, various resistance welding and flame cutting equipment, both manual and automatic. Manual experience will be just sufficient to become acquainted with the feel of the process for those who have not had this experience. The effect of different variables will be studied with the automatic equipment. Sample welds will be saved for the physical testing laboratory. The cathode ray oscillograph will be used to show the action of resistance welding controls.

Weld Testing.—Tensile tests of arc welds, gas welds, flash welds, spot welds; bend tests; hardness tests. Arc welds, as-welded and stress relieved, made with bare and covered electrodes will be tested. Magnetographic inspection of welds with prepared defects will be carried out.

Particular Information

Date.—The course will begin Wednesday, November 2, 1938.

Expense.—The tuition for the course will be one hundred dollars for the basic four weeks, and an additional twenty-five dollars for the optional two weeks.

Limitation of Enrollment.—The intensive nature of the course and the close personal attention given to each student make it necessary to limit the number of men who will be accepted.

Application for Admission.—Applications for this course should be received not later than October 1, 1938. All communications with regard to the course should be addressed to Professor Wendell F. Hess, Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, New York.

TRANSIT MEETING

New York, September 25th—For the first time in its history, the American Transit Association and its subsidiaries will convene beyond the borders of the United States, when on Oct. 2nd, at Toronto, Canada, it opens its five day discussion of transit affairs at the Royal York Hotel. The subsidiaries of the American Transit Association joining in the meeting are the American Transit Association Bus Division, the American Transit Association Interurban Division, the American Transit Engineering Association, the American Transit Purchases and Stores Association, the American Transit Operating Association, the American Transit Claims Association, and the American Transit Accountants' Association. The convention will be the associations' 57th annual meeting, and will be attended by more than 1000 delegates.

Representing better than 200 of the leading companies operating street cars and buses, trolley coaches, subway, elevated and interurban lines as well as 134 manufacturers of public transportation equipment in the United States and Canada, the delegates will devote one day to play and four days to intensive study of

transit problems as they pertain to transit operation and to the 12 billion passengers carried annually by these companies.

Questions of modernization of equipment, labor, public relations, finance, maintenance, engineering and related subjects will be dealt with first by prepared addresses from recognized experts and then by general discussion upon the convention floor.

GERMAN CONVENTION

On September 15th–18th the joint meeting of the German Acetylene Society headed by Dr. Rimarski and the Society for Gas Welding headed by Dr. Kessner was held in Braunschweig. The following papers were presented:

1. Non Destructive Testing of Welded and Hardened Parts, by Dr. Berthold.
2. Mechanical Tests for Gas Welded Joints, by Dr. Dümpelmann.
3. Gas Welding Boiler Plate, by Dr. Weidle.
4. Economizing on Materials in Hand Work by Gas Welding, by Mr. Colbus.
5. Research Work of the Welding Institute of the Braunschweig Technical College: Gas Welding and Hardening of Gray and Malleable Cast Iron; Oxygen Cutting of Metals, by Professor Kritzler.
6. Welding Non-Ferrous Metals with the Oxygen-Butane Torch, by Mr. Thürnau.

WILLIAM H. GIBB

The Thomson-Gibb Electric Welding Company of Lynn, Massachusetts has announced that Mr. William H. Gibb of the Thomson-Gibb Company has established offices at 101 North 33rd Street, Philadelphia from which he will serve the Philadelphia territory which includes eastern Pennsylvania, southern New Jersey, Delaware, Maryland and Virginia.

Mr. Gibb has had a great many years of experience in the field of resistance welding, having founded and served as president of the Gibb Welding Machines Company of Bay City, Michigan, until it was merged with the Thomson Company in 1929 to form the Thomson-Gibb Electric Welding Company.

STAINLESS STEEL BULLETIN

Arcos Corporation, Philadelphia, Pa., has issued its illustrated Technical Bulletin No. 3. The bulletin contains new and previously unpublished information on the physical and metallurgical characteristics of stainless and special alloy welding.

Bulletin No. 3 also includes a complete Alloy Welding Manual for the engineer and the operator.

13TH INTERNATIONAL ACETYLENE CONGRESS TO BE HELD IN MUNICH

The 13th International Congress of Carbide, Acetylene, Oxyacetylene Welding and Allied Industries will be held in Munich, Germany, from June 25 to July 1, 1939. The three preceding Congresses were held in Zurich in 1930, in Rome in 1934 and in London in 1936.

The purpose of the Congress is to promote and discuss all questions of scientific, technical and economic nature which are related to the preparation and uses of calcium carbide, of acetylene and of the oxyacetylene process. Because of its importance for metal fabrication, the field of oxyacetylene welding will receive special emphasis. The other related technical fields will also be given full attention, particularly the use of acetylene as the starting point in making chemical products.

Lectures and reports by internationally known experts are planned for the Congress. Sessions will be devoted to the following subjects:

1. Manufacture of Calcium Carbide
2. Acetylene as the Starting Point for Organic Compounds
3. Acetylene Illumination (Acetylene Lighting, Marine Illumination, Light Signals, etc.)
4. Gases (Especially Acetylene and Oxygen)
5. Apparatus and Machines for Oxy-Acetylene Welding
6. Metallurgy of Welding, Cutting and Flame-Treating
7. The Technique and Application of Oxyacetylene Welding and Cutting
8. The Technique and Application of Flame-Treating
9. Mechanical Testing Procedures

9a. Non-Destructive Testing Procedures

10. Set-ups for Welding and Cutting
11. Operator Training
12. Safe Practices and Protection for Welding Operators
13. Motion Pictures
14. Exhibits

An international technical exposition, to be held simultaneously with the Congress, is intended to show the present status of each of these fields. A series of films have been prepared for the same purpose.

Official inquiries should be directed to the office of the Congress in Berlin-Friedenau, Bennigsenstraffe 25, Berlin, Germany. Lectures and reports should be sent to the Office of the Congress, from which they will be forwarded to the proper places. Lectures and reports should be in the Office of the Congress by February 1, 1939, at the latest.

It is anticipated that the lectures and entertainment will be held in the assembly rooms and lecture hall of the German Museum in Munich. The technical exposition will also be held in the German Museum.

WELDING TORCH BULLETIN

The Victor Equipment Company of 844 Folsom Street, San Francisco, Calif., has just issued a very attractive catalog describing their line of torches and accessories. It also contains some very useful information on selection of size of tip, maintenance and flame adjustment.

WELDING MAKES THE GRADE

The Riddell Corporation, Bucyrus, Ohio, which manufactures road machinery, reports that the use of welding in the construction of road graders not only results in more rigid equipment but cuts costs

Road-Grader Frame Arc Welded

approximately 15 per cent and reduces the amount of maintenance required after the equipment is in service.

WELDING HOLDS

During the recent hurricane, a long, overhead, welded steam line at the Merrimac Division of the Montsanto Chemical Co. was blown down and bent up pretty badly. This had been supported about 20 feet above the ground and contained a 20-foot expansion section. Notwithstanding the rough treatment, not a seam let go and it is carrying steam as usual even though it is lying on the ground in a mass of wreckage.

3-In. Welded Steam Line After the Hurricane. Not a Joint Let Go. It is Still Carrying Steam as Usual

BRIDGE FOR COAL AND COKE HANDLING

Indicative of the trend in materials handling systems is an order for a modern coal bridge received by Dravo Corporation, Pittsburgh, Pa., from Kokancoal

Company, Inc., of Brooklyn, N. Y. This will be the largest shuttle boom and man trolley type bridge ever built for coal and coke handling, and it will be used on the Newtown Creek for unloading these commodities from steamers and barges into bins for subsequent dumping into trucks, or onto a storage pile, or from the storage pile into bins as may be required.

A major part of the shop fabrication work will be welded.

The employment of a man trolley on this type of equipment is a new feature in bridge crane construction. The trolley rail will be 65 feet above ground level, and the bridge will have a span between supporting legs of 180 feet. The boom will cantilever 65 feet over the land-side leg and 90 feet beyond the water-side leg. A Hayward two-line, power wheel bucket, capable of handling $2^1/_2$ tons of coal with each grab, will be used, and it will reach over the water as much as 65 feet.

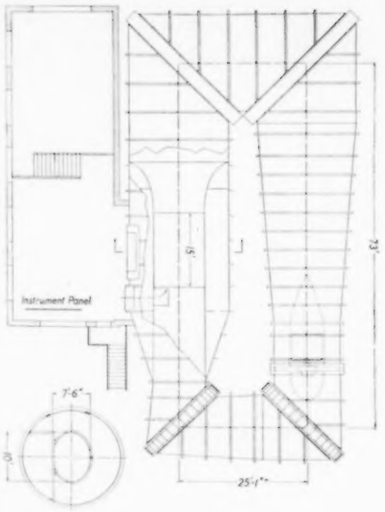
The bridge will travel on a curved runway along the dock for a distance of over 600 feet. To permit this travel, it will be necessary to provide special trucks capable of being driven either simultaneously or in independent manner. The length of bucket travel from barge to bin may be as much as 335 feet, and the rate of bucket travel, combining the movements of both shuttle boom and the man trolley, will attain a speed of 1200 feet per minute. It is estimated from these facts that the bridge will have an unloading capacity of about 200 tons an hour when dumping on the storage pile, with each round trip of the bucket consuming three-fourths of a minute; the longer trip to the bins will require about one minute.

The trolley will be equipped with a scale for weighing the coal as it is hoisted in the bucket, and this weighing will be automatically performed and recorded.

It is expected that the bridge in question will be completed sometime in January 1939.

NEW WIND TUNNEL

Progressive improvement in welding methods and materials, and the important position which welding has achieved in the industrial picture during recent years, are once again spotlighted by the completion of the first welded steel high pressure wind tunnel of its type to be built in the United States. The tunnel will permit the testing of scale airplane models under simulated conditions such as would be encountered in the substratosphere, and also at flying speeds as high as 400 miles per hour. Since no existing tunnels available for commercial testing are able to create such conditions, and the need was realized, the Massachusetts Institute of Technology Corporation authorized the staff of the Guggenheim Aeronautical Laboratory, headed by J. C. Hansacker, to proceed with the erection of such a tunnel. Work was done under the supervision of Dr. H. Peters, Asst. Prof. of Aeronautical Engineering. Contract for the structural design, fabrication and erection of the unit was awarded the Pittsburgh-Des Moines Steel Co., Pittsburgh, Pa., and work was begun in October 1937. Jackson & Moreland, Boston, Mass., were the supervising engineers.



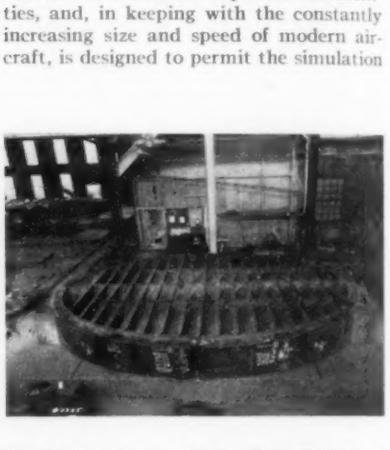
General Plan of Wind Tunnel

The new tunnel is of electric-arc-welded steel plate construction, plates varying from $^3/_8$ inch to 1 inch in thickness, and consists of conical and cylindrical tubes arranged to form a rectangle measuring 44 x 89 ft., and to make a closed circuit 196 ft. 2 inches in length along the center line. Inside diameter varies up to 19 ft. 4 inch maximum. The steel plates were formed at the Neville Island, Pa., plant of the contractor, and the edges prepared for the butt-welded joints either by planing or by machine flame cutting. Welded units were built-up for shipping, and final assemblies made at the site to form the complete tunnel. The tunnel was built in accordance with the Code of the American Society of Mechanical Engineer's Unfired Pressure Vessels Section of the Boiler Code. It is estimated that more than three miles of welding rod were used in assembly.

Upon completion, the structure was subjected to an hydrostatic test to a gage pressure of 54 pounds per square inch without the development of a leak in any of the welded seams or joints, nor was there any indication of weld failure or weakness. This test also served partially to stress relieve the tunnel, since the test pressure was 25% in excess of the intended working pressure. This excess pressure, by prestressing the metal at the points where shrinkage or secondary stresses are close to the elastic limit of the metal, serves to insure adequate fatigue endurance for the life of the tunnel.

Wind Tunnel Under Construction

The tunnel, which has been named the Wright Brothers Wind Tunnel, was formally inaugurated on September 12 with ceremonies attended by Orville Wright and other prominent aeronautical engineers. The unit represents a progressive addition to aviation's experimental facilities, and, in keeping with the constantly increasing size and speed of modern aircraft, is designed to permit the simulation of flying conditions in the substratosphere and to provide effective air stream speeds beyond the capacity of existing wind tunnels now available for commercial testing. Wind velocities up to 400 miles per hour, and pressures ranging from $^1/_4$ to 4 atmospheres absolute can be created for tests. Models having wing spreads up to 8 feet can be accommodated.



Elliptical Girders to Which Were Welded Air Stream Direction Vanes Presented a Complicated Engineering Problem. Here Is Shown a Completed Vane Section on the Floor of the Fabrication Shop of the Pittsburgh-Des Moines Steel Co.

Air is forced around the tunnel by a 12 ft. $11^3/_4$ inch diameter propeller driven by a 2000 horsepower A.C. motor having four speeds from 450 to 1200 r.p.m. The air stream is turned around the corners by means of welded crescent shaped vanes so designed that the air flow direction is changed efficiently and in such a manner that a uniform cross section of air velocity is maintained.

The test section inside the tunnel is of wooden construction and is in the shape of an ellipse 7 ft. 6 inches high, 10 ft. wide and 15 ft. long. All test data is recorded from this section by means of electrically operated recording instruments.

The Wright Brothers Wind Tunnel will be put to use immediately testing various aircraft models under different pressure and wind velocity conditions, and will also be used during the college year for the instruction of undergraduate aeronautical engineers.

ANNUAL REPORT ACTIVITIES OF THE AMERICAN WELDING SOCIETY

Year Ending October 15, 1938

By P. G. Lang, Jr., President

During the past year the American Welding Society has continued to function as an agency for the coordination of welding activities in the United States, the assembly, codification and distribution of knowledge relating to this and associated subjects. The tangible results and evidences of its progress are enumerated in the various pertinent sections of this report. The interests of standardization and uniform practice have been advanced. The cooperation of other technical organizations has been invited, with a view to the avoidance of unnecessary labor and overlapping of activities, to the end that, in all points of contact with other fields, coordination may be effected in the manner best calculated to yield satisfactory results.

With the emergence of the Society from its formative period, much thought has been given to defining more precisely the lines along which its future activities are to be directed. In accordance with a policy enunciated a year ago, revision of the by-laws with a view to facilitating its development as a technical organization was undertaken. These suggested revisions, formulated after careful study, were approved by the Board of Directors, redrafted by the Committee, and again presented to the Directors, and submitted to the membership, for approval. As finally adopted, May 1, 1938, these amendments are of a nature designed to make the Society a strong technical organization, and to increase its efficiency and usefulness.

Various committees have been appointed to study the organization, past activities and general character of the Society, the nature and value of its accomplishments, and to recommend a definite course to govern its future development. Among these is the new Committee on Outline of Work, appointed at the beginning of 1938, to coordinate the Society's technical activities, stimulate progress and introduce the maximum standardization and uniformity in the codes and technical reports. In the brief period of about nine months since its organization the accomplishments of this Committee, working under the Chairmanship of our incoming President, Mr. H. C. Boardman, have been substantial, and include the formulation of a code of rules for the operation of technical committees.

During the past administrative year the Board of Directors held two meetings and the Executive Committee five meetings. The matters considered and acted upon by these bodies included the revision of by-laws, already mentioned, to provide for reduction in the number of Directors, to make the Board a more workable body; election of a Treasurer for a term of three years; tightening of membership requirements; reduction in return to sections on membership dues without undue hardship on the sections, particularly those newly organized.

The name of the body controlling the award of medals and prizes was changed to "Board of Awards," as it was believed that the designation "Board of Trustees" was a misnomer. The functions of the Board were enlarged to cover the Lincoln Gold Medal, Industry and Welding cash prizes and any other awards coming under the jurisdiction of the Society, in addition to the Samuel Wylie Miller Memorial Medal. The Board of Awards formulated new rules to cover these awards, which, after acceptance by the donors, were approved by the Directors, and are now in effect. The 1937 Miller Memorial Medal, the 1938 Lincoln Gold Medal with accompanying certificates, and the Industry and Welding Cash Prize will be presented at the opening sessions of the Annual Meeting, in accordance with the foregoing regulations.

When it was found that the first year's operation of extended activities had not produced sufficient revenue to enable the Society to embark upon the desired program of increased technical activities nor to reduce the amount of underwriting required for the second year's operation of the extended activities program, the appointment of a committee to study the situation and report thereon was authorized. The findings and recommendations of this Committee were considered at the Executive Committee meeting July 15, 1938, which was attended by representatives of the contributors to the underwriting fund. The matter was thoroughly discussed, and the recommendations as finally adopted included the abolition of the office of Managing Director. Pursuant to these recommendations, the Committee was authorized to prepare a new program of extended activities with budget, for submission to and approval by the Underwriters, and ultimate approval by the Board of Directors.

More intimate association and more effective cooperation of the various sections is assured by the formulation of a definite schedule of regional conferences, at which the accumulated experience of wide areas may be discussed, and information exchanged. The first District Meeting of the Society, held in conjunction with the Western Metals Congress and Exposition, occurred at Los Angeles, California, during March of the present year. Six West Coast Sections participated. The mornings were devoted to technical sessions, the afternoons and evenings to inspection tours, entertainment and visits to the exposition. Due largely to the unstinted efforts of the Los Angeles Section, this gathering was a great success, and a source of encouragement in connection with arrangements for other meetings of a similar character. It was my own privilege and pleasure to attend this gathering, and, en route, to visit several sections, and to investigate welding activities and the Society's sphere of influence in the region between the Mississippi River and the Pacific Coast. In addition to Los Angeles, my itinerary included visits to San Francisco, Salt Lake City, Denver, Lawrence and Kansas City. At the University of Kansas, Lawrence, Kansas, I was able to attend the Fourth Annual Welding Conference of that region, and at Denver and Kansas City I attended meetings of the local sections. The conditions which I observed were certainly most satisfactory, and augur well for the future of welding in the regions concerned.

Our monthly organ, The Welding Journal, has amplified and improved its contents. A new and appropriate cover design, featuring outstanding developments in welding, has been adopted. A growing volume of instructive and interesting articles, which reflect the mounting accumulations of knowledge on the subject of welding, fills its pages, and, in every respect, it compares most favorably with other technical papers. One of the major objects of publishing in this magazine the various articles, codes, etc., which it contains is to elicit the comments and criticisms of our members and readers of the Journal. The Society can best fulfil its appointed function if all members will freely submit their comments and suggestions on such matters.

The Research Supplement of The Welding Journal and the monthly bulletins of the Welding Research Committee continue to chronicle the progress of systematic and organized research, while the benefits of experience acquired on a variety of special problems or under peculiar conditions are made available to the member who regularly peruses the articles appearing in the Journal, and who thus acquires information which it would be impossible to obtain from any other source. The Journal's growth is concretely illustrated by the fact that the number of pages comprised in the issues for the year ending September 1938, was 1290, as compared with 995 pages in the previous year, or an increase of about 30 per cent. The Journal has further been expanded to include a New Products Section, but this innovation is as yet too new to permit an accurate appraisal of its worth. Appreciation of the importance of the Journal, and of its value as a medium for reaching a wide circle of prospective users is represented by the increasing volume of advertisements which it carries month by month. Upon recommendation of the Publication Committee the advertising and subscription rates were advanced, because of increased membership resulting in expanded circulation.

During July 1938, the "Welding Handbook," sponsored by the Society, and in process of development for some time, appeared. This work of about twelve hundred pages represents a digest of World experience to the date of its publication, and the associated labors of ninety authors and two hundred and thirty-seven reviewers. Welding in each of the phases of its application, as well as its economic aspect and general theory, is discussed. For the splendid accomplishment represented in this handbook great credit is due the Editorial Committee, under the Chairmanship of Dr. D. S. Jacobus. While a careful analysis of the financial phase and distribution of the book is reassuring, the Editorial Committee, particularly three of its members, who have agreed to underwrite the Society against loss, are left with some responsibilities.

The spread of the Society's work throughout the country is represented by about forty local sections, which, with few exceptions, are in reasonably satisfactory condition. During the past year fifteen new sections have been formed. While some of these sections are still unable to meet the new requirement of the by-laws that they have twenty-five qualified A, B and C members, the indications are that special efforts will be made within the next few months to acquire this complement. In addition to meetings, inspection tours and social gatherings, the activities of the local sections include lecture courses and the arrangment of Welding Conferences. During the past year the Headquarters organization, with the cooperation of the local sections, has compiled a Guide for the Operation of Sections, which embodies the procedure recommended for the conduct of affairs of existing sections and those in process of formation. This Guide also contains Standard By-Laws for Sections, prepared by the By-Laws Committee, and approved by the Executive Committee.

That membership in the AMERICAN WELDING SOCIETY is world-wide is evidenced by admissions sought and obtained in regions as remote as South Africa. Under the efficient leadership of Mr. A. F. Davis our Membership Committee has been successful, as shown by a gain of 39.2 per cent during the past year. On October 1, 1937 our membership totaled 2541; on the same date in 1938 the figure was 3538.

Divided according to the various classes of membership the gains are as follows:

Sustaining Members	12
Members	422
Associate Members	336
Operating Members	182
Student Members	45
Total	997

Graphic chart showing growth of membership is included in this report.

In accordance with our usual custom, the formal official financial statement will be presented to the Board of Directors by our Treasurer, Mr. C. A. McCune, and will be printed in the Society's Year Book. Any one desiring detailed information in the meantime can obtain it from the Financial Committee or the Board of Directors.

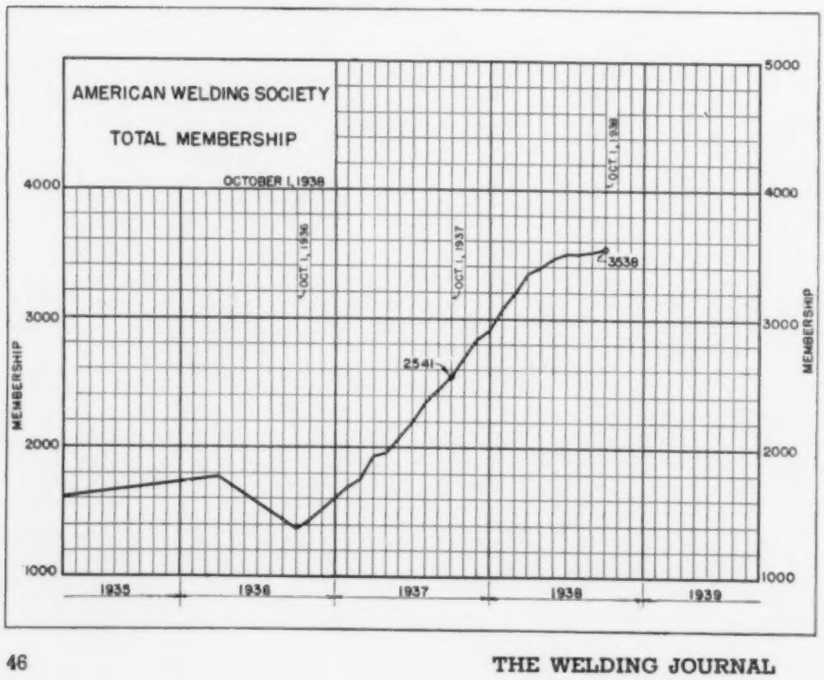
The Society's finances, as they stood at the end of September 1938, are briefly summarized as follows:

ASSETS $8012.64
LIABILITIES $2988.25
NET WORTH $5024.39

As a result of our growing numbers and activities, it seems probable that increased office force and facilities will be necessary in the not distant future, and, in this connection, we thank our friends of the National Electrical Manufacturers Association for a timely gift of office equipment, released incident to changes in its Pittsburgh Offices, and forwarded to our New York establishment.

The authoritative status now universally accorded to the Society is the fruit of its work during the period of nearly twenty years since its original formation. The splendid results which we can record have been made possible only by the devoted and effective work of its membership, to whom, on behalf of the Society and myself, I wish to express unbounded gratitude. I take the liberty of reiterating my conviction that effective work by isolated individuals is possible only in rare cases, and the best results are obtainable only through collaboration of effort and judgment. This observation applies with particular force to an organization concerning itself with such a subject as welding, where the united efforts of persons whose technical education and experience differ widely are essential to success. We must further remember that even persons of the highest technical attainments require assistance in promulgating the results of their work.

In transferring the office to my successor I have the sincere and well-grounded hope that the loyal and helpful attitude which has characterized my own administration will be continued, and that, building on the foundation of past accomplishments and the cooperation of his associates, Mr. Boardman will conduct the Society to new heights of achievement.



Summary of Committee Activities

Committee on Building Code

The provisions of our Building Code have now been adopted by more than two hundred municipalities, including the great metropolitan centers of New York, Chicago and Baltimore.

During the early part of 1938 this Committee issued a revision of Code 1, Part A, as the edition of 1937. It has cooperated with the Board of Standards and Appeals of New York City in formulating rules for fusion welding under the new City Building Code, and has also acted on inquiries from various cities and sections of the Society regarding building code matters. The Committee is endeavoring to draft changes in the clause relating to qualification procedure to conform to the A. W. S. Standard Qualification Procedure.

It is now considering the possibility of presenting during the coming year, for the first time, illustrative details of welded connections which have been found satisfactory in building construction.

Committee on Welding Bridges

The Specification for the Design, Construction, Alteration and Repair of Highway and Railway Bridges by Fusion Welding, released in the Spring of 1936, has continued to find an expanding field of application. It has been approved by the American Railway Engineering Association, and is to be published as an appendix in the 1938 Edition of the American Association of State Highway Officials Bridge Specifications.

As our Bridge Specification is applied to actual practice the lessons of experience are carefully recorded for use as a basis of revision along the lines of conformity to field and shop requirements. A permanent committee has been charged with the duty of considering revisions, and issuing periodically successive editions of the specification, which will embody progressive modifications and improvements. As a result of slightly more than two years of practical experience, the first of these amended editions, that of 1938, is now in approximately complete form, and its appearance may be anticipated in the near future.

Committee on Inspection Method Used in the Manufacture of U-69 and U-70 Pressure Vessels

This Committee has completed its assignment, and the results of its work are represented in a report, which was accepted by the Board of Directors at its meeting February 24, 1938.

Committee on Large Welded Pipe for Hydraulic Purposes

Since the publication of my predecessor's Annual Report, in which the work of this Committee as it then stood was reviewed, the tentative draft of code prepared by it has been the subject of a large volume of comment, criticism and suggestion, on the basis of which an amended version, now in process of development, is being prepared.

One phase of this work instances the cooperative attitude displayed by the AMERICAN WELDING SOCIETY in its relations with other bodies, since The American Water Works Association is formulating a somewhat similar code with particular reference to the lower pressure range, and our representatives have contacted the officers of that organization, with a view to insuring the maximum harmony between the major requirements of the two codes.

Committee on Nomenclature, Definitions and Symbols

The Committee on Outline of Work recommends the discharge of this main committee; consequently its current report consists of the reports of its two subcommittees, namely:

Symbols.—The AMERICAN WELDING SOCIETY Committee on Symbols is also a Joint Committee of the American Standards Association on the same topic. Some minor changes have been suggested in the AMERICAN WELDING SOCIETY report on this subject, and, if these are adopted by both organizations, these symbols will become the American Standards.

Definitions and Chart—A master chart of welding processes and definitions of terms appearing on the chart have been approved and published. Report covering chart and revision of definitions, published in 1929, is in process of development, and will be submitted to the Committee, for approval, at the Annual Meeting.

Committee on Pressure Piping

This Committee has held one meeting, on which occasion consideration was given to Chapter 3 of the American Society of Mechanical Engineers Code for Pressure Piping, relating to the Welding of Pipe Joints. A large portion of this chapter was reviewed, and some changes introduced. Other parts of the chapter were referred to subcommittee for further study.

It is anticipated that another meeting of the Committee will be held in the near future, and that its work will be completed during the present autumn.

Committee on Standard Qualification Procedure

During the past year this Committee has revised the AMERICAN WELDING SOCIETY'S "Tentative Rules for the Qualification of Welding Processes and Testing of Welding Operators," giving these rules the title of "Standard Qualification Procedure." While there are many methods of welding, some of which may not require a standard qualification procedure, it was felt by the Committee that the manual arc and gas welding processes demanded immediate attention. Therefore, the "Standard Qualification Procedure" was reported upon as "Section 1—Manual Arc and Gas Welding." This Standard Qualification Procedure has been approved by the Board of Directors, and printed in pamphlet form by the Society.

A round-table discussion of the Standard Qualification Procedure is to be held during the Annual Meeting at Detroit, with a view to obtaining expressions from all who may desire to submit criticisms or suggestions. Suggestions along the lines of simplifying the present rules will be encouraged. The Committee will further consider the possibility of simplifying the present rules, and to the extension of these or similar rules to other forms of welding than those now covered by the Standard Procedure.

American Welding Society Conference Committee with American Society of Mechanical Engineers Boiler Code Committee

During the past year this Committee has continued its cooperation with the A. S. M. E. Boiler Code Committee in the consideration of problems referred to it. Within this period its work has been peculiarly light, since but two problems have reached it from the A. S. M. E. Committee, namely:

PROBLEM LIII—Relating to the use of non-ferrous materials for welded pressure vessels.

PROBLEM LIV—Relating to the reduction of ductility with increase of strength in welded joints.

Study of Problem LIII has led to the extended use of welded construction with non-ferrous materials, and in connection with Problem LIV the Boiler Code Committee is now assembling experimental data.

Committee on Rules for Welding of Oil Storage Tanks

The report of this Committee, under the title of "A. W. S. Tentative Rules for Welding of Oil Storage Tanks," was issued during June in preprint form, and was published in the August number of THE WELDING JOURNAL. The Committee was appointed at the Society meeting held in the autumn of 1933, and its report is the result of work which proceeded continuously from the early part of 1934.

It is the belief of the Committee that adherence to these rules assures safe and durable tank construction. In the development of its report our Committee worked in close cooperation with a Committee of the American Petroleum Institute that prepared purchase specifications for the construction of such large storage tanks, namely those of the above-ground type which are too large to permit shop construction and shipment by cars or trucks. After extended discussion and investigation the rules embodied in the report of our Committee were so prepared as to be suitable for use as the welding section of the A. P. I. purchase specifications for such tanks.

Committee on Rules for the Welding of Gravity Tanks, Tank Risers and Towers

The first edition of these rules, issued by the National Board of Fire Underwriters, in 1935, was based on information and suggestions furnished by our Committee, which served in a joint capacity as representatives of the AMERICAN WELDING SOCIETY and the International Acetylene Association. As a result of about two years of experience in the application of these rules, modifications and improvements were suggested, and, after further study of the subject by our Committee in conjunction with the Committee of the I. A. A., a revision of the rules was completed, and published in the May 1938, issue of THE WELDING JOURNAL. Preprint copies of the report were issued by the headquarters office of the Society, in March 1938.

Committee on Standard Tests for Welds

The first draft of "Standard Methods for Mechanical Testing of Welds," prepared in 1937, was distributed and discussed at the Annual Meeting of the AMERICAN WELDING SOCIETY, in October of that year. A number of revisions were agreed upon, and other matters were referred to a subcommittee for study. In June 1938, a revised draft was sent to the representatives of other Committees for study, and a few minor modifications have been suggested. A meeting of the Committee is to be held during the Annual Meeting of the Society, at Detroit, on which occasion these final revisions will be made, and the "Standard Methods for Mechanical Testing of Welds" approved for submission to the Society.

More important than the completion of these new "Standard Methods" is the fact that, largely on the basis of the general agreement reached at these meetings, such changes have already been made in the weld-testing methods provided in other general specifications as to greatly reduce the undesirable variation.

Educational Committee

This Committee has completed two of its assignments, namely:

Outline of an Educational Program to be conducted by local sections

Outline of suggested welding courses in engineering schools and colleges

The Committee is now in readiness to cooperate with local sections in the establishment of an educational program, and also with schools and colleges in the arrangement of courses in welding engineering.

Committee on Welding in Marine Construction

Tentative Rules for Fusion Welding Steam, Oil or Air Piping in Marine Construction, formulated by this Committee, appeared in the April 1938, issue of THE WELDING JOURNAL. These rules apply to piping for working pressures in excess of 100 lb. per sq. in. The purpose of their publication was to obtain the benefit of comments, criticisms and suggestions.

Filler Metal Specifications Committee

This Committee has canvassed producers and users of filler metal in an effort to obtain criticisms of the Filler Metal Specification prepared jointly by the AMERICAN WELDING SOCIETY and the

American Society for Testing Materials. It is anticipated that a report of this Committee will be in readiness for submission at the Annual Meeting of the Society, at Detroit.

American Welding Society Representation in Other Technical Bodies

Any report on the technical activities of the AMERICAN WELDING SOCIETY would be incomplete without reference to its very extensive representation in other technical bodies, which assures the mutual advantages of intimate collaboration, extending the influence and prestige of our own organization, and obtaining for ourselves the benefits to be derived from worldwide research and experience. The status of such representation as it exists at this time is as follows:

American Society for Metals—Recommended Practice Committee

Our representative has assisted in the development of the new A. S. M. Handbook. This work has involved proofreading, editorial comments on various articles and the preparation of matter on the Welding of Stainless Chrome Iron.

American Standards Association—Sectional Committee on Electrical Definitions

Our representative reports that these definitions are now in the final stages of completion, and that the work will be finished in the near future.

American Standards Association Sectional Committee on Electric Welding Apparatus

There is nothing new to report for the current year. Steps have been taken toward the establishment of Proposed International Standards, but progress along these lines must await the result of a meeting of the International Electromechanical Commission, held at Torquay, England, in June.

American Standards Association Sectional Committee B-5 on Electric Welding Dies and Electrode Holders

No meeting of the Committee was held during the year.

American Standards Association Sectional Committee A-57 on Building Code Requirements for Iron and Steel

Our representative has recommended that this Committee adopt the Building Code Welding requirements as promulgated by the AMERICAN WELDING SOCIETY.

American Standards Association Sectional Committee Z-5 on Ventilation Code

This Committee has not been active during the past year.

American Standards Association Sectional Committee Z-2 on Code for Protection of Heads, Eyes and Respiratory Organs of Industrial Workers

The Sectional Committee has completed a revision of this code, with the extended scope noted in the A. S. A. Year Book for 1938. Following approval by the sponsor, the National Bureau of Standards, it has been submitted to the A. S. A. for approval as an American Standard, and it is expected that action will be taken as soon as a few matters of detail have been clarified.

American Standards Association Sectional Committee Z-28 on Work in Compressed Air

The code-drafting committee of the sectional committee is approaching the completion of its task. It is now awaiting some additional data which are to be furnished by the United States Navy Department. The draft will be placed in the hands of the sectional committee as soon as possible after this material has been made available to the drafting committee.

American Society for Testing Materials Subcommittee B-5 on Copper Alloys

Committee B-5 has held the following meetings during the year:

Rochester, N. Y.—March 9th
Atlantic City, N. J.—June 30th

Association of American Railroads—Committee on Fusion Welded Tank Car Tanks

No meeting of this Committee was held during the year, but our representative reports that the construction of a limited number of tank cars has been authorized, and these are undergoing service tests.

National Research Council

The Division held no meeting, its activities being conducted by correspondence. The only matter claiming its attention which even indirectly related to welding was the taking of initial steps for the formation of a clearing house to facilitate the interchange of information on various projects in process of investigation by laboratories throughout the country.

National Board of Boiler and Pressure Vessel Inspectors

The Executive Committee of the National Board of Boiler and Pressure Vessel Inspectors has held nine meetings during the past year, which were usually concurrent with meetings of the American Society of Mechanical Engineers Boiler Code Committee. In cooperation with the latter Committee the National Board takes a very active interest in the administrative questions connected with boiler and pressure vessel legislation in the various states. The National Board devotes a great deal of attention to uniformity of application of the safe practices recommended by the Boiler Code Committee, and up to date, has succeeded in extending its activities to twenty-three of the States of the Nation.

Manufacturers' Committee

During the past year the Manufacturers' Committee negotiated with the American Society for Metals in connection with the financial arrangements for the Society's participation in the 1938 Western Metals Congress and Exposition, and in the 1938 National Metals Exposition and Congress. The Committee considered the feasibility of holding definite regional conferences with exhibits to take the place of the present Welding Conferences and exhibits at the various Universities. However, no recommendation has been offered as yet. The Committee also recommended that our Society become active in having welding recognized in the engineering courses of universities. This matter was referred to the Committee on Outline of Work, for study.

Committee on Outline of Work

The Committee on Outline of Work was appointed about the first of the year with the broad purpose of coordinating the technical activities of the Society and for stimulating progress in such activities.

The Committee has held several meetings and has disposed of a number of matters by correspondence.

The Committee formulated a set of Rules relating to policy matters governing Technical Committee activities and the relation of technical committees to the Committee on Outline of Work. These Rules are being presented to the Board of Directors for consideration and adoption.

Some of the recommendations made by the Committee on Outline of Work and adopted by the Board are:

1. The appointment of a Pressure Piping Committee identical in personnel with the Committee on Pressure Piping—Welding Fabrication of the American Standards Association.
2. Appointment of a small committee to look into the need for standardization of training and qualification of Welding Inspectors.
3. Appointment of a small committee to suggest ways and means for the promotion of Welding education in engineering schools.
4. Appointment of a joint committee with American Water Works Association for the welding of elevated storage tanks.

It has also looked into the personnel and made recommendations in regard thereon in connection with the Committee on Building Codes and representation on A. P. I. Subcommittee on Field Welding of Casings.

It has attempted correlation and coordination between the Definitions Committee, Standard Qualification Procedure, Building Code Committee, Oil Storage Tank Committee, Symbols Committee and Hydraulic Pipe.

All in all, the Committee believes that there is a definite need for some such coordinating committee as the Committee on Outline of Work and that such a committee can perform a useful and important function.

Welding Research Committee

The work of the Welding Research Committee is becoming an established, recognized institution. Its pronouncements and findings carry weight all over the world. Leading articles and research reports published here and abroad carry bibliographic references to reports or reviews issued by the Welding Research Committee.

So far the work has been concerned largely with critical digests of the literature, making available translations of important articles to research workers and others interested, and the conduct of relatively small, but important, pieces of fundamental research in our leading universities. This year, however, has witnessed the financing of one of the major projects of the Industrial Research Division, namely, the Fatigue Strength of Welded Joints. Some $25,000 in cash is assured for this investigation, and subgroups have been appointed to plan the details of this program. No doubt this amount will grow as industry realizes the opportunities of cooperative investigation in this field, and makes use of the facilities provided at the University of Illinois for testing large-size specimens. A fellowship was created at Rensselaer Polytechnic Institute in resistance welding, and grants-in-aid have been given to several selected universities for support of specific researches.

During the year ending September 1938, the Committee will have published a total of 452 printed pages as Research Supplements to THE WELDING JOURNAL. Thirty translations have been made available. Of the reports published, 24 relate to the Fundamental Research Division, 10 represent critical digests of the literature, 4 Industrial Research reports and 4 reports directly under the auspices of the Main Committee. The Committee has maintained direct contacts with the universities and industrial laboratories throughout the country, and during the year a representative from the central offices has visited 40 universities, and 4 industrial and governmental laboratories. These visits will continue as time and money permit.

There are many inter-related accomplishments which are bearing fruit. For example, an exchange arrangement with the British Institute of Welding now makes available the results of a $30,000 program of the British Institute to our own research workers.

There have been numerous gatherings of committees and subcommittees, bringing together the welding research workers of this country. New committees have been organized under the Industrial Research Division. Joint meetings have been held with the American Society for Testing Materials and the AMERICAN WELDING SOCIETY. Another fundamental research conference is scheduled for Detroit in October. At this time some 17 research reports will be presented by members of the Fundamental and Industrial Research Divisions. Some 70 investigations are now under way in the leading universities in this country.

The Committee has been indeed fortunate in having the wholehearted support of The Engineering Foundation financially. This support and interest continues to be one of the best assets of the Committee in attracting funds from Industry, and cooperation elsewhere. For example, the specimens furnished the research workers in the universities, and the committees of the Industrial Research Division, already amount to many thousands of dollars a year, as do also special services in the way of translations, mimeographing facilities and the like.

The original purpose of The Engineering Foundation in setting up the Welding Research Committee to provide for united and cooperative action in solving scientific welding research problems, and encouraging research workers in the welding field is being accomplished. We look forward to the continuance of this work, with some assurance that when times are better the activities of the Committee will grow and become increasingly useful.

OHIO STATE OFFERS NEW WELDING COURSE

Columbus, O., Sept.—A new curriculum in Ohio State University's college of engineering leading to a degree in welding engineering is announced for the autumn quarter starting October 4th.

Investigations by a committee of department chairmen, in consultation with industrial representatives, reveals a "healthy demand" for men with the specific training to be offered in the new welding curriculum.

"In view of the phenomenal strides of welding in all types of heavy goods industries and in the transporation field there are prospects that this branch of professional engineering will be stable for many years to come," according to Dean Charles E. MacQuigg.

Further evidence of off-campus enthusiasm for the proposal has come in the agreement of a prominent Ohio State alumnus to sponsor the project in its formative period. Joining with him are prominent manufacturers interested in the fields of electric, gas and other types of welding. This sponsorship, Dean MacQuigg points out, assures close contact with latest industrial developments, while at the same time the sponsors leave the curriculum and subject matter entirely to the college of engineering.

Administration of the curriculum will be under the department of industrial engineering which for a number of years has presented the shop courses in welding required by various curricula in the engineering college. Entrance requirements are the same as for the other curricula of the college of engineering and admissions will be in the hands of the Entrance Board at Ohio State, to which inquiries should be directed.

Welding engineering students will take the same work as other engineering students the first year, amounting to 58 academic hours. For succeeding years they will have the courses and hours here listed: mathematics (calculus), 15; physics, 19; mechanics, 18; metallurgy, 10; economics and accounting, 16; mechanical engineering, 19; drawing (work drawings, technical sketching), 3; English, 3; electrical engineering, 8; civil engineering (trusses), 5; industrial engineering, 41; welding (applications), 11; military science, 3. From 11 to 14 hours electives also will be permitted.

"The curriculum, embracing all branches of modern welding, such as electric, gas, resistance, etc., is an attempt to meet the need for a training for men desiring to specialize in this comparatively new technology," Dean MacQuigg says. "It seeks to supplement the training of civil, metallurgical, industrial, and mechanical engineers, each with some of the training of the others.

"Because of the rapid growth of the art and the very special techniques involved, there has been little opportunity for the design practices to become rationalized. Until lately the operations have been largely empirical. In view of the quite involved relationships between the nature of the metal to be welded, the design of the joint, the practice used in manipulation of the torch or electrode, the nature of the filler metal the heat treatment effects and other important factors, the routine production of welds has become a highly specialized practice in every aspect.

"Amazing progress has been made in both the technique and exploitation of welding but it has been delayed because of the lack of specially trained engineers. For example, the civil engineer, competent to design the welded joints and to properly distribute stresses among the members of a structure, frequently lacks the knowledge of how the welding operation might affect the properties of the metal involved. Progress made has been almost always dependent upon the cooperation of several kinds of engineers."

PURDUE UNIVERSITY ORGANIZES SCHOOL OF CHEMICAL AND METALLURGICAL ENGINEERING

For many years past, Purdue University has maintained an active School of Chemical Engineering, the enrollment of which has steadily increased, the 1938 graduating class numbering 91 men. Early in the history of the School the practice of permitting some undergraduate specialization in chemical engineering and related fields was adopted; to give effect to this policy three options (general chemical engineering, organic technology and metallurgy) were provided, each intended to furnish opportunity for upper class courses of instruction in the several specialties.

This arrangement was, for a long time, eminently satisfactory; in recent years, however, the increasing complexities of each of the fields of engineering has necessitated a reconsideration of the curriculum as the result of which it has become obvious that, related though they are, first class instruction in chemical engineering and metallurgical engineering can be provided only by completely separating the courses of study.

This reorganization, which has just been completed, has resulted in the establishment of a School of Chemical and Metallurgical Engineering which is headed by Dr. John L. Bray, head of the former

School of Chemical Engineering and an engineer of extensive industrial experience. The new School will provide curricula leading to the degree of Bachelor of Science in Chemical Engineering, Bachelor of Science in Metallurgical Engineering, Master of Science and Doctor of Philosophy.

WELDING DEMONSTRATION TO BE GIVEN BY HAWAIIAN SECTION FOR SUGAR TECHNOLOGISTS

The Hawaiian Section of the AMERICAN WELDING SOCIETY will give a welding demonstration and an exhibit of welding applications of interest to those connected with the sugar industry in the Territory of Hawaii, during the annual meeting of the Sugar Technologists in Honolulu beginning November 14, 1938. The program is scheduled to last approximately 2½ hours and will be held at the shops of The Islands Welding & Supply Co., Ltd.

Welding is playing an increasingly important part in the production of Hawaii's $76,000,000 annual sugar crop. Mill buildings, cane grabs, rakes, cars, irrigation pipe lines, steam lines, stainless steel tanks and an infinite variety of all-welded items are used to help produce the Territory's Chief staple product.

It is the aim of the Hawaiian Section of the AMERICAN WELDING SOCIETY to present a program of timely interest to the Plantation Managers, engineers, mill superintendents and agricultural experts who will attend the Sugar Technologist's Annual meeting. Demonstrations of multi-flame pipe welding, under-water cutting, hard-surfacing and machine flame-cutting are planned along with exhibits of used hard-surfaced farm implement parts, welded cane machinery, all-welded trusses, steps in the welded fabrication of stainless steel and a complete line of welding and cutting equipment will be on display.

The motion picture "Haynes Stelliting the Plowshare," will be shown. This film gives step-by-step details for preparing the plowshare and shows proper application of the hard-facing alloy. The convincing presentation of the many economies and advantages of hard-facing is certain to be of interest to the Sugar Technologists.

SECTION ACTIVITIES

BIRMINGHAM

At a meeting of the Executive Committee of the Birmingham Section held on the afternoon of October 14th, Mr. Julian Adams was appointed to fill the vacancy caused by the death of Mr. L. E. Cobb, as Vice-Chairman of the Section. Mr. E. W. Braun was appointed Chairman of the Membership Committee. Mr. Braun will appoint the members of his Committee at a later date. The Committee agreed that Mr. F. E. McAtee, Chairman of the Program Committee, has made excellent progress with the programs of the Section.

Meeting of the Section was held in the evening of the same day in the Auditorium of the Alabama Power Building. There was a total attendance of 55. The attendance at this meeting was small because of several other meetings being held on the same night. Mr. E. C. Chapman, Metallurgist of the Combustion Engineering Company, spoke on "Welding the Alloy Steels."

Mr. J. E. Durstine of The Lincoln Electric Company, very ably discussed for the benefit of the meeting, assisted by Mr. W. J. Sanneman, Mr. R. W. Sandelin's article "The Simple Steel Analysis and Its Relation to Quality in Steel," which appeared in THE WELDING JOURNAL for September.

Meetings tentatively scheduled for the next couple of months are:

November—L. C. Bibber, Welding Engineer, Carnegie-Illinois Steel Co. Subject: Welded Joints—Which Ones to Use and When and Why.

November—Elmer Isgren, Supt., R. G. LeTourneau Inc.

December—A. E. Gibson, President, Wellman Engineering Company.

January—F. C. Fantz, Vice-President, Midwest Pipe & Fittings Co.

CHICAGO

With more than 170 present the Chicago opened its 1938-39 meetings with a talk by Elmer Isgren, superintendent, R. G. LeTourneau Inc., Peoria, Illinois, manufacturers of earth moving equipment. The management of The Link-Belt Company, 300 W. Pershing Road, provided an excellent meeting room and a get-together dinner before the meeting.

Mr. Isgren described and illustrated with lantern slides many of the novel applications of welding for which his company has long been noted. It is not unusual for a piece of equipment to be fabricated and be put in use even before the design has been developed in the drafting room. A knowledge of welding, extending through many years, makes it possible for Mr. Isgren and his department to carry out these unusual developments, many of which are ready for operation almost overnight.

CINCINNATI

This Section is cooperating with all the local sections of all the other national engineering societies through association with the Technical and Scientific Societies Council of Cincinnati. The University of Cincinnati Evening College, in cooperation with the Cincinnati Section is offering two ten-week lecture-demonstration courses this year on welding. These are not shop courses. They are designed for engineers and production executives, for the supervisory personnel in design and maintenance, for welding foremen, draftsmen and designers.

The October meeting held on the 10th was addressed by J. D. Gordon of Taylor-Winfield Corporation, on the subject "Design and Building of Fabricated Machine Structures," which was accompanied by movies.

COLORADO

The first Fall Meeting of the Colorado Section was held on September 14th. At this meeting there was an attendance of approximately 60. The speaker of the evening was Lieut. Commander Chas. M. Johnson of the U. S. Navy. His subject was the welding and inspection of welds on welded ships in the Brooklyn Navy Yard.

At the October meeting, held on the 12th, Mr. R. McBrain, testing engineer of the Denver, Rio Grande & Western Railway, talked on the subject of detecting defects in welds by the use of Magna-Flux. His talk was illustrated.

On November 9th, Mr. F. C. Hutchison, Manager of The Linde Air Products Company of Kansas City, Mo., will talk on the subject of Flame Hardening and Flame Cutting.

At the January meeting it is expected to have Mr. J. F. Lincoln of the Lincoln Company.

At a meeting of the Executive Committee, Mr. R. P. LeBaron was appointed Vice-Chairman of the Denver Section.

GEORGIA

At a meeting on October 3rd, the following officers were elected for the balance of the 1938-39 season.

Chairman—George Bird, Bird Potts Company.

Vice-Chairman—D. B. Hunt.

Secretary-Treasurer—Arthur McCoy, Calvert Iron Works.

HAWAII

The following are the newly elected officers of the Hawaiian Section:

Chairman—E. E. Heacock.

Vice-Chairman—Robert Plaus.

Secretary-Treasurer—J. D. Mardick.

Executive Committee (2 years)—P. Orso, W. E. Smith, A. N. Mullin.

The regular monthly meeting was held on August 25th at the Oahu Country Club House. The Chairman spoke at length about the welding demonstration described elsewhere in this issue. Mr. C. J. Erickson was appointed as Chairman of the Publicity Committee to act in conjunction with the Executive Committee to advertise the merits of welding, especially among engineers, architects and prospective building owners.

Mr. B. P. Carpenter represented the Section at the Annual Meeting of the Society in Detroit.

The next regular meeting of the Section will be held at Waikiki Lau Yee Chai's. An instructive sound film approved by the Underwriters was shown. The film presented an interesting insight to the wide facilities of the Underwriters' Laboratories.

LOS ANGELES

The November meeting of the Section will be held on the 17th. Dr. Donald S. Clark of the California Institute of Technology, will be the speaker. His subject will be "Grain Size and Physical Properties of Weld Deposits."

A Christmas Party will be held on December 15th.

The January meeting will be on the 9th. The subjects covered will be "Repair of Steel Castings by Welding" and "Underwater Welding and Cutting." Speakers will be announced later.

It has been decided that another educational course will be presented this coming year by the Los Angeles Section, on the welding of pressure vessels and pressure piping. Mr. Turner C. Smith is Chairman of the Committee. Further details will be given later as soon as the date has been decided upon.

Mr. Harold Etter of the Air Reduction Sales Company has been appointed Chairman of the Membership Committee and at the present time is actively at work to increase the membership of the Section.

MONTANA

The Montana Section has established a permanent address as follows: Box 1787, Fort Peck, Montana.

The Montana Section has just completed a very successful summer season. Much of the success of the monthly meetings can be attributed to the outstanding papers which were presented before the meetings.

At the June meeting an illustrated paper on "Hard Facing" was presented. This paper was prepared by the members of the staff of the Great Northern Tool and Supply Company of Billings, Montana. Following the paper there was a lively discussion in which the members related experiences and difficulties encountered in various hard facing applications.

The July meeting was held July 6th. A paper entitled, "Welded Steel Structures" prepared by the Lincoln Electric Company was presented. The text of the paper was supplemented by motion pictures and slides which served to illustrate the various points discussed in the paper.

Mr. Charles F. Garmon, Secretary-Treasurer of the Section resigned his office inasmuch as he was leaving Fort Peck. Mr. T. B. Jefferson, one of the organizers of the Section, was elected to complete Mr. Garmon's unexpired term.

A paper prepared by Mr. A. E. Gibson, Past-President of the AMERICAN WELDING SOCIETY was read by Mr. William Galloway before the August meeting of the Montana Section. This paper with its many slides illustrated the manner in which welding is used by industry in the fabrication of heavy structural and mechanical equipment items, such as, clam shell buckets, coke oven doors, gas producer shells, watch case vulcanizers and many other items of similar nature. Following the reading of the paper there was a lengthy discussion of the features presented and many of the slides were reshown.

A paper prepared and presented by Mr. C. W. Capper formed the nucleus of the September meeting of the Section. This paper was entitled: "The Testing of Welding Operators and Welding Electrodes." Mr. Capper in his capacity of supervisor of tests at the U. S. Engineer Shops, was able to show why so many welders failed to meet the requirements of the welding test of the U. S. Engineer Department. He also pointed out how the method of application would have a material effect upon the physical characteristics of the deposited metal in the making of all-weld test specimens of welding electrodes.

Two papers made up the program of the October meeting of the Montana Section. The first of these papers entitled, "Welding Rod Coatings" was presented by Mr. T. B. Jefferson, while the second paper "Progress in Pipeline Welding" was read by Mr. A. F. Chan. Messrs. Jefferson and Chan are associated with the U. S. Engineer Department at Fort Peck, Montana, in the capacity of Engineer-in-charge of Shops and Foreman of the Welding Shop, respectively.

Both papers brought out many interesting facts. The mystery that is always connected with welding rod coatings provoked a spirited discussion following the presentation of the paper on that subject.

The next meeting of the Montana Section will be held November 2nd in the Administration Building Auditorium, Fort Peck, Montana.

NEW YORK

The first technical meeting of the New York Section was held on Tuesday, September 27, 1938, and was a joint meeting with the Metropolitan Section of the American Society Mechanical Engineers.

The meeting featured the welding of high-pressure piping in large power stations in the New York area, and specifically, the "Welding Experiences at the Waterside Station of the Consolidated Edison Company of New York" as discussed by Mr. W. J. Angus, Assistant Mechanical Plant Engineer, and "Welding High-Pressure Piping in Essex Generating Station" by H. Weisberg, Assistant Mechanical Engineer, Public Service Corporation of New Jersey.

The meeting was attended by some 300 members and guests and a very lively and enlightening discussion ensued.

The New York Section has completed plans for its third evening lecture course. The program this year will use as a text the new welding handbook of the AMERICAN WELDING SOCIETY, amplifying the remarks of the various scheduled speakers which will be presented in an original and instructive manner.

The lectures will include the following subjects:

November 22nd—Fundamentals of Welding Processes.

November 29th—Metallurgy, Welding of Carbon and Low Alloy Steels.

December 6th—Welding of Nickel and Its Alloys and Welding of Nickel Steels.

December 20th—Aluminum Alloys. Copper and Copper Alloys.

January 17th—Qualification Inspection.

January 24th—Testing Procedure and Physical Properties of Welds.

January 31st—Structural Welding—Ships.

February 14th—Structural Welding—Bridges.

February 21st—Design of Welded Machinery.

February 28th—Design of Welded Pressure Vessels.

March 14th—Design of Welded Piping.

March 21st—Estimating Welding Construction.

NORTHERN NEW YORK

The following are the list of Officers, Executive Committee and Committees for 1938-39 of the Northern New York Section.

Chairman—F. H. Miller, 1st Vice-Chairman—R. W. Clark, 2nd Vice-Chairman—W. C. Hutchins, Secretary-Treasurer—G. A. Ross.

Executive Committee—M. Unger and R. L. Browne (terms ending May 31, 1939), E. J. Myers and T. R. Lawson (terms ending May 31, 1940), E. F. Potter and E. R. Spittler (terms ending May 31, 1941).

Membership Committee—E. F. Potter, Chairman, W. E. Wilson, Vice-Chairman, J. H. Humberstone, N. W. Owen, J. Ransom, J. Lipsky, G. G. Somerville and J. J. McAuliffe.

Meetings & Papers—B. C. Tracey, Chairman, A. C. Stevens, R. A. Gilbert and W. B. Lair.

Public Relations—L. D. Meeker, Chairman, L. R. Leveen and J. E. Waugh.

NORTHWEST

The first meeting of the current season was held on September 21st and was addressed by James F. Lincoln, President, The Lincoln Electric Company, who spoke on the subject of "Welding vs. Prejudice Both Here and Abroad." There was an unusually large attendance of both members and especially invited guests, among the latter being many of the principal executives of the industrial plants of Minneapolis and St. Paul. Mr. Lincoln covered the subject in a most interesting way, which held the undivided attention of all those present.

The Program Committee have prepared a most interesting schedule of meetings for the current season as follows:

Oct. 26th—G. V. Slottman, Assistant Manager, Applied Engineering Department, Air Reduction Sales Co., New York, "Flame Hardening."

Nov. 16th—G. O. Hoglund, Welding Engineer, Aluminum Company of America, Jobbing Division, Development Section, New Kensington, Pa., "Welding Aluminum and Its Alloys."

Dec. 14th—Speaker to be announced.

Jan. 25th—M. S. Clark, President and General Manager, The Federal Machine & Welder Company, Warren, Ohio, "Latest Development in Resistance Welding."

Feb. 15th—C. E. Swift, Welding Engineer, The American Brass Company, Waterbury, Conn., "Welding Copper and Copper Alloys."

Mar. 15th—V. N. Krivobok, Associate Director of Research, Allegheny Steel Company, Brackenridge, Pa., "Stainless

Steel and Other Welding Characteristics."

Apr. 19th—Everett Chapman, President, Lukenweld, Inc., Coatesville, Pa., "Welded Steel Construction."

May 17th—E. F. Smith, District Manager, Haynes Stellite Company, Chicago, "Hard Surfacing."

OKLAHOMA CITY

The 1938-39 season of the Oklahoma City Section started with the meeting held Tuesday, October 4th, and as one of the boys expressed it, "the season started with a bang."

The meeting was called at 6:45 at which time about 40 members and friends enjoyed the sociability that prevailed around the dinner table. During the dinner entertainment was furnished by Mr. Leon Paris who rendered popular selections on the accordian and entertained otherwise by humorous monologues.

The more serious portion of the program was opened by the showing of motion pictures furnished through the courtesy of the Bastian-Blessing Company. These films were very interesting and showed in very effective manner the wide application of gas cutting and gas welding.

The speaker of the evening was E. J. Brady, Manager of the Stainless and Alloy Division of the Hollup Corporation, whose subject was, "The Arc Welding of Stainless Steel."

The interest in the subject was evidenced by the type and number of questions asked the speaker at the close of his talk.

The attendance including those who came for the meeting only, was the largest in number of any meeting held since the section was organized and it certainly was a representative group. It included students and their teachers, operator welders and their foremen, job shop owners, state inspectors, engineers and metallurgists.

OMAHA

The October meeting of the Omaha Section was held on the 13th. Mr. Stanley Reiff of the General Construction Company discussed his paper on all-welded bridges for secondary roads, which paper won a $200 prize in the recent Lincoln Foundation Contest.

PEORIA

On September 7th the Peoria Section held their first formal meeting, having as its guest speaker, Mr. Harry Boardman, Research Engineer of the Chicago Bridge and Iron Works, who spoke on the welded construction of storage tanks. This meeting was thrown open to all individuals interested in welding. The attendance was approximately 50.

After the talk was given by Mr. Boardman, the members of the Section remained for a closed meeting during which elections of officers was held.

The following are the officers elected for the coming year:

Chairman—E. E. Isgren, R. G. LeTourneau, Inc.

Vice-Chairman—H. D. Wiese, Superior Welding Co.

Secretary—Walter J. Brooking, R. G. LeTourneau, Inc.

Treasurer—G. A. Sively, Micro Products Co.

Executive Committee (2 years)—John F. Reist, Keystone Steel & Wire Co.; Arthur G. Filker, Reliance Welding Co.; Robert Rutledge, A. Lucas & Sons.

(1 year)—George R. Roberts, National Cylinder Gas Co.; Guy B. Arthur, The Chas. E. Beadaux Co. of Ill.; W. I. Miskoe, The Lincoln Electric Company.

PHILADELPHIA

The regular monthly meeting of the Philadelphia Section was held on October 24th. Mr. O. C. Frederick of the General Electric Company, spoke on the subject, "Developments in Resistance Welding."

The following are the meetings scheduled up to May 1939. All are to be held in the Engineers' Club, Philadelphia.

November 21, 1938—8 P.M., "Stainless Steel Welding and Design."

January 16, 1939—8 P.M., "New Applications of Gas Welding."

February 20, 1939—8 P.M., "Residual Stresses."

March 20, 1939—8 P.M., "Structural Design and Welding."

April 17, 1939—8 P.M., "Steel Casting and Plate Fabrication." (Joint Meeting with American Foundrymen's Assn.)

May 1939—Annual Inspection Trip.

PITTSBURGH

The opening meeting of the Pittsburgh Section was held October 26th, at which time Mr. F. H. Frankland, Chief Engineer, American Institute of Steel Construction, spoke on "Welding in the Structural Field."

The second meeting scheduled for the Fall Season will be held Wednesday night, November 16th, at which time Col. G. F. Jenks, Chief of Ordnance Department, U. S. Army, will speak on "The General Subject of the Application of Welding to Ordnance."

All meetings this year will be held in the beautiful Mellon Institute of Industrial Research, 4400 Fifth Avenue, Oakland, the Pittsburgh Civic Center. The officers of the Pittsburgh Section feel extremely well pleased that they have been able to secure such a splendid meeting place and feel it will add considerably to the prestige of the Section. Only meetings of highly scientific and technical importance are permitted to be held in this auditorium.

ROCHESTER

The first meeting of the 1938-39 season was held on Thursday, October 6th, in the Todd Union, River Campus, University of Rochester. Mr. H. R. Bullock, a recent instructor at Massachusetts Institute of Technology, and now a Welding Engineer, gave a very good talk on the "Weldability of Low Alloy Steels."

The Rochester Section is conducting an Educational Course at the University of Rochester. Prof. W. J. Conley has charge and the course meets every other week.

The November meeting will be held on November 3rd in the Todd Union, University of Rochester and the speaker will be Dr. G. V. Slottman of the Air Reduction Sales Company, whose subject will be "Flame Hardening."

The December meeting will be on December 1st and the speaker will be Robert T. Gillette of the Works Laboratory, General Electric Company. His subject is "Resistance Welding."

ST. LOUIS

The October Meeting of the St. Louis Section held on the 14th had Mr. F. C. Fantz, Vice-President, Midwest Piping & Supply Co., as the speaker. His subject was "The How and Why of Regulating Bodies and Their Relations to the Welding Industry."

SAN FRANCISCO

The first regular monthly meeting of the season was held in the Auditorium of the Alameda High School, on September 23rd. There were 97 members and guests present. Mr. Leo Edelson, representative of the Handy & Harman Company, gave a very interesting lecture and demonstration for a period of forty minutes on the subject of Low Temperature Brazing. This was followed by a series of demonstrations for smaller groups of twenty at a time.

SAN JOAQUIN VALLEY

With an attendance of over one hundred, the monthly meeting of the San Joaquin Valley Section, was held on September 22nd in Bakersfield. The program as presented was enthusiastically received, and following the paper presented by Mr. A. P. Maradudim, Materials Engineer, El Segundo Refinery, Standard Oil Company, many questions were asked regarding the subject matter of his paper. A number of members of the San Joaquin Valley Chapter of the American Petroleum Institute were also present.

Mr. H. H. Hammett asked to be excused from the post of Chairman of the Program Committee. Mr. R. Rutherford of The Linde Air Products Company was named to fill the position.

The schedule of meetings starting in September up to June 1939 are all to be held on a Thursday night. The time and place of the meetings are as follows:

October 27th—Taft, California
November 24th—Bakersfield, Calif.
December 15th—Taft, Calif.
January 26, 1939—Bakersfield, Calif.
February 23, 1939—Taft, Calif.
March 23, 1939—Bakersfield, Calif.
April 27, 1939—Taft, Calif.
May 25, 1939—Bakersfield, Calif.
June 8, 1939—Taft, Calif.

TULSA

The opening Fall Meeting of the Executive Committee held at Hotel Tulsa for the purpose of appointing Committees for the duration of present Officers' terms. The Committees are as follows:

Membership Committee—R. L. Looney, Chairman, Big Three Welding Equipment Co., C. L. Wiley, P. W. Patterson, H. H. Bassett, F. J. Thompson, S. M. McManus and L. E. Lippincott.

Program Committee—O. L. Rogers, Chairman, Big Three Welding Equipment Co., C. D. Laidley, J. B. Davis, L. M. McKelvey, H. M. Rosevear and Louis R. Hodell.

Codes Interpretative Committee—C. G. Wells, Chairman, National Tank Co., E. F. Kinsvauter, L. R. Hodell, M. E. Clauson, C. L. Wiley, S. L. Spence, A. A. Adcock, P. W. Patterson, Chas. McNamar and J. H. Smythe.

WASHINGTON

The Washington Section has made application for membership in the District of Columbia Council of Engineering and Architectural Societies.

A dinner meeting was held on October 4th at the Lafayette Hotel. Following the dinner, there was a regular meeting at which Mr. A. E. Gibson, President of the Wellman Engineering Company was the guest speaker. Mr. Gibson talked on "Welding of Low Alloy Structural Steels." There were eighty present at the dinner and one hundred at the meeting.

The following is the program for the ensuing year:

November 22nd—"Welding Nickel Base Alloys," F. G. Flocke, International Nickel Co.

December 12th—"Flame Cutting, Flame Hardening and Flame Softening," Joint A. S. M., J. J. Crowe, Mgr., Apparatus Research and Development Dept., Air Reduction Sales Company.

January 24th—"Non-destructive Testing of Welds," N. L. Mochel, Metallurgical Engr., Westinghouse Elec. & Mfg. Co.

February 28th—"Metallurgy of Welding," J. C. Hodge, Chief Metallurgist, The Babcock & Wilcox Co.

March 28th—"Large Welded Tanks of Cylindrical, Spherical and Spheroidal Shapes," H. C. Boardman, Chicago Bridge & Iron Co.

April 25th—(Dinner Meeting) F. T. Llewellyn, Research Engr., U. S. Steel Corp.

LECTURES

November 2nd—"Designing for Structural Welding," F. H. Dill, Mechanical Engr., American Bridge Co.

February 8th—"Welding Design," C. H. Jennings, Research Engr., Westinghouse Elec. & Mfg. Co.

March 15th—"Gas Welding and Cutting," H. H. Moss, Linde Air Products Co.

April 12th—"Welding Copper Base Alloys," I. T. Hook, The American Brass Co.

List of New Members

September 1 to September 30, 1938

CANADA

Gratton, Yvon (C), Labelle, Que., Canada.
Hall, A. J. (D), 272 Wellington St., Sarnia, Ont., Canada.

CHICAGO

Brandsma, R. (D), 237 W. 105th Place, Chicago, Ill.
Curry, R. A. (B), 1621 E. 78th St., Chicago, Ill.
Guirl, H. P. (C), The Superheater Co., East Chicago, Ind.
Pearson, W. C. (B), Westinghouse E. & M. Co., 20 No. Wacker Drive, Chicago, Ill.
Rutt, E. M. (D), 338 N. Lockwood, Chicago, Ill.

CINCINNATI

Baechle, E. J. (B), The Stacey Mfg. Co., Elmwood Place, Cincinnati, Ohio.
Gornall, E. (D), Littleford Bros., 453 E. Pearl St., Cincinnati, Ohio.
Harris, A. M. (B), Littleford Bros., 453 E. Pearl St., Cincinnati, Ohio.
Pandorf, F. O. (B), The Stacey Mfg. Co., Elmwood Place, Cincinnati, Ohio.
Wielftange, F. H. (C), Wielftange Mfg. Co., 828 Belle Ave., Hamilton, Ohio.

COLUMBUS

Jones, A. B. (B), 1459 W. 6th Ave., Columbus, Ohio.

CONNECTICUT

Petsche, R. A. (C), U. S. Submarine Base, New London, Conn.
Sharp, H. P. (C), The Bristol Co., Waterbury, Conn.

DETROIT

McKesson, L. E. (D), 309 Fulton St., Buchanan, Mich.

GEORGIA

Guillot, Edward (B), 282 Spring St., N. E., Atlanta, Ga.
Minch, W. T. (C), 569 Techwood Drive, Apt. 33, Atlanta, Ga.

INDIANAPOLIS

Spoon, Robert (D), 2828 E. Michigan St., Indianapolis, Ind.

KANSAS CITY

Ashton, N. L. (B), 1012 Baltimore Ave., Kansas City, Mo.
Buxton, M. L. (D), Longview Farms, Lee's Summit, Mo.
Darby, H. C. (C), Inland Steel Co., 922 Walnut St., Kansas City, Mo.
Fizzell, J. L. (B), 1611 Crystal Ave., Kansas City, Mo.
Ladd, R. J. (C), Dept. of Shop Practice, Kansas State College, Manhattan, Kansas.
Marsh, Marvin B. (B), 7100 Roberts St., Kansas City, Mo.
McCune, L. C. (D), Longview Farms, Lee's Summit, Mo.
Smith, V. M. (B), 1411 Haskell Ave., Lawrence, Kansas.

LOS ANGELES

Grant, E. G. (C), California Inst. of Tech., 1201 E. California St., Pasadena, Calif.

MILWAUKEE

Barkow, E. F. (C), Wisconsin Bridge & Iron Co., 5023 N. 35th St., Milwaukee, Wis.
Cauntley, Clifford (F), 2336 W. Juneau Ave., Milwaukee, Wis.
Sarvis, A. L. (D), 7828 Milwaukee Ave., Wauwatosa, Wis.

NEW YORK

Grap, Alexander (D), 318-31st St., North Bergen, N. J.
Klinke, H. O. (B), 10 Monroe St., Apt. Hd 12, New York, N. Y.
Weekes, James H. (C), 125 W. Main St., Oyster Bay, N. Y.

WESTERN NEW YORK

Patterson, J. K. (D), 29 Leverette St., Fredonia, N. Y.

NORTHWEST

Dahlquist, C. E. (C), Butler Mfg. Co., 900—6th Ave., S. E., Minneapolis, Minn.
Steinmetz, Leslie (C), 4006 Emerson Ave., No., Minneapolis, Minn.
Tritchler, W. C. (C), Smith Welding Equip. Corp., 2633 4th St., S. E., Minneapolis, Minn.
Weisgerber, L. J. (C), 3537 1st Ave., Minneapolis, Minn.

OKLAHOMA CITY

Helderman, J. E. (D), 940 S. W. 28th St., Oklahoma City, Okla.

PEORIA

Wiese, H. D. (B), Superior Welding Co., 331 Knoxville Ave., Peoria, Ill.

PHILADELPHIA

Johnston, Bruce (B), Fritz Engrg. Lab., Lehigh University, Bethlehem, Pa.

PITTSBURGH

Callery, S. S. (C), Box 242, Finleyville, Pa.

ROCHESTER

Barker, J. A. (D), 104 Wilder St., Rochester, N. Y.
Le Cain, G. H. (C), 275 Park Ave., Rochester, N. Y.
Jansen, C. C. (D), 382 Clifford Ave., Rochester, N. Y.
Marr, Phillip (D), 93 Michigan St., Rochester, N. Y.
Martin, N. N. (B), Foster Wheeler Corp., Dansville, N. Y.
Mitchell, H. F. (D), 72 Francis St., Rochester, N. Y.
Owen, E. V. (D), 442 Pullman Ave., Rochester, N. Y.

ST. LOUIS

Wilfley, Joseph (F), R. F. D. 4, Fulton, Mo.

SAN JOAQUIN

Edleman, L. A. (C), American Potash & Chem. Corp., Trona, Calif.

SOUTH TEXAS

Beeley, Raymond (B), 301 Frio St., Houston, Texas.
Glover, W. B. (D), Wyatt Metal & Boiler Wks., Box 3052, Houston, Texas.
McLaren, L. G. (D), Wyatt Metal & Boiler Wks., Box 3052, Houston, Texas.

WASHINGTON, D. C.

Endlich, P. M. (C), 3300—19th St., N. W., Washington, D. C.
Jeffries, W. J. (C), Bureau of Construction & Rep., U. S. Navy, Washington, D. C.
Macintosh, C. D. (C), 1910—37th St., N. W., Washington, D. C.
Sampson, D. S. (C), A. M. Byers Co., 1127 Shoreham Bldg., Washington, D. C.
Smith, W. W. (C), 3008 Second Road, N., Arlington, Va.
Warriner, R. E. (B), International Nickel Co., 915 Shoreham Bldg., Washington, D. C.

WICHITA

Galley, John (C), Cozine & Galley Mach. Co., 320 E. 21st St., Wichita, Kansas.
Nellans, H. M. (C), Vickers Petroleum Co., Potwin, Kansas.
Tibbets, R. J. (C), Sinclair Ref. Co., Pipe Line Dept., 1412 Commerce Bldg., Wichita, Kansas.

NOT IN SECTIONS

Hlusicka, J. (C), C. P. C. Maracaibo, Mene, Grande, Venezuela, South America.
Martinson, E. O. (C), American Mach. & Metals, Inc., E. Moline, Ill.
Powers, H. C. (C), American Air Filter Co., 215 Central Ave., Louisville, Ky.
Reed, Clarence (D), Box 865, Vernon, Texas.
Roman, Ing. H. (B), Cales Victoriei 50 Scara C, Bucarest, Roumania.
Ross, D. H. (B), Michigan Power Shovel Co., Benton Harbor, Mich.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-287. Welder desires position. Can do all types of welding. Fifteen years experience in burning, cutting and welding. Arc and gas welding of boilers, piping, etc. Just finished doing high-pressure piping welding for the War Department.

A-288. Designer for Resistance Welding machines. Experienced in design of jigs, fixtures, special tool and special automobile parts, also for special research apparatus and equipment. Special designer at Guggenheim School of Aeronautics at the California Institute of Technology. Chief Engineer and Superintendent of Machinists at the Daniel Guggenheim Airship Institute in Akron, Ohio. Designer for spot, butt, press, flash and seam welders, portable gun welders, projection welders, etc.

A-289. Welder desires position. Two and a half years' experience in all position electric welding on both maintenance and production work. Has had a limited amount of gas welding experience. Young man, single, free to go any place.

A-290. Position wanted as welding shop superintendent or work on welded construction in Engineering Department. 10 years experience in Engineering Departments doing designing, layout, estimating and production control, also time-study, rate-setting, estimating, costs, etc.

A-291. Electric Welder. Worked for the Shell Union Oil Co. on tank building; The American Locomotive Co. on water tight tanks; Chicago Bridge and Iron Co. and the Dolomitre Marine Corp. Had a Class A rating with these companies. Also experienced with the Acetylene torch on the cutting of metals.

POSITIONS VACANT

United States Civil Service Examination. Junior Engineer, $2000 a year. Optional Subjects: 1. Aeronautical. 2. Agricultural. 3. Architectural. 4. Ceramics. 5. Civil. 6. Electrical. 7. Mechanical. 8. Naval architecture. 9. Structural steel and concrete. Applications must be on file with the United States Civil Service Commission at Washington, D. C., not later than the following dates: (*a*) *November 14, 1938*, if received from States other than those named in (*b*) below. (*b*) *November 17, 1938*, if received from the following States: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon Utah, Washington, Wyoming.

MINIATURE STEEL PLANT

Through use of a miniature steel plant, the first of its kind in the steel industry, a unique approach to research is being made in the new research and development laboratory of the Jones & Laughlin Steel Corporation, Pittsburgh.

Tapping the Small Open-Hearth Furnace Which Has a Capacity of 1500 Pounds and Parallels Conditions in the Big Steel Furnaces in the J & L Works. It Is a Recuperative and Not a Regenerative Furnace and Features an Unusual Type of Burner. The New Type of Construction in the Furnace, Which Was Developed by the Research Staff, May Be Applicable to Open-Hearth Furnaces Used in Actual Production

An Ingot from the Open Hearth Is Being Rolled on This Small Mill to Form a Bar Which Will Be Subjected to Any of a Number of Tests to Determine Its Physical Properties.

Here steel making facilities such as an open-hearth furnace, heat-treating furnaces and rolling mills of pilot plant size are used in conjunction with extensively equipped chemical, physical and metallographic laboratories in a direct approach to solving the problems of steel quality.

This pilot plant of small manufacturing units will be used to investigate, with complete technical control, the various methods of steel making on a basis that enables the ready application of new and improved practices in the big furnaces and mills of the production departments.

In the past, it has been the general practice to conduct research by a laboratory procedure which resulted in advancements being made in research faster than they could be tested and applied in the mills.

The J & L research and development department overcomes this handicap by combining the research laboratory with an assembly of development equipment to form this unusual laboratory in which steel making practices can be studied on a small scale resembling mill conditions so that when new or improved practices are turned over to the mills, they are certified to be commercially practicable. In addition, the staff is working to develop new designs for furnaces which give promise of bettering the quality of steel.

The research and development division is under the direction of H. W. Graham, General Metallurgist, which insures that the attention of the research staff, under H. K. Work, Manager, is directed toward current problems and facilities the coordination of their work with the metallurgical departments in the mills. This general direction also concentrates the research and development activities, yet separates them from the routine metallurgical control work carried on in the works at Pittsburgh and Aliquippa.

The laboratory is divided into several divisions. Projects are assigned to each division on the basis of the general fields of science or activity covered by that division such as physical metallurgy, process metallurgy, pilot plant operation, machine shop and testing, library and patent division and the service and clerical divisions.

The aim and scope of the research and development division determined that the

department should be housed in a factory type building adjacent to the works. The central shop is flanked by offices and laboratories with adequate provision for future expansion. Electric power, compressed air, steam and other services are supplied from the mills nearby.

The type of equipment used in the new laboratory has been governed by the desire to give primary attention to the processes of steel making. A feature of this equipment is the small open-hearth furnace developed by the staff which has a capacity of 1500 pounds and parallels conditions in the big steel furnaces in the works. It is a recuperative and not a regenerative furnace, and is equipped with an unusual type burner. The new type of construction in this experimental furnace may be applicable to big furnaces used in actual production.

Ingots cast from this furnace weigh from 185 to 900 pounds as compared with ingots from commercial production which weigh from $3^1/_2$ to 10 tons. The laboratory ingots are rolled in the pilot plant or, in some special cases, are rolled into various products on equipment in the regular mills.

WELDED STEEL CONSTRUCTION

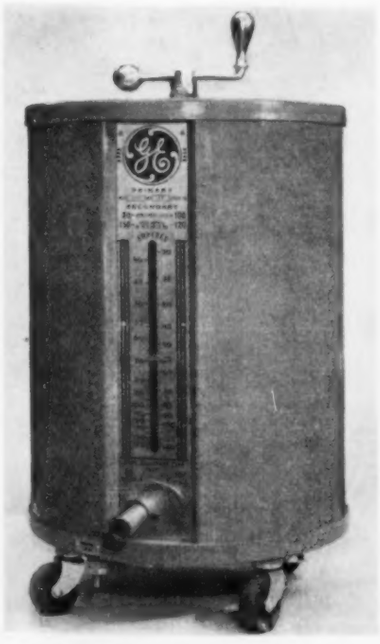
A new book has just been published by the Pitman Publishing Corporation, 2 West 45th Street, New York, on "Welded Steel Construction," by Robert S. Hale. This book sells for $3.00 and is a manual for the design, detail and fabrication and erection of welded steel buildings, bridges and other steel structures. The books consists of 169 pages copiously illustrated.

NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

FOR LIGHT-GAGE WORK

A new 150-ampere alternating current arc welder of the transformer type has been developed by General Electric for low current welding with heavily coated alternating current arc welding electrodes. While it is chiefly intended for use on light-gage metals, its wide welding range—35 to 180 amperes—permits its use on fairly heavy materials as well.



G. E. Arc Welding Transformer

With this type of equipment, power costs are reduced approximately 50 per cent as compared to welders of the rotating type. In addition, it avoids troublesome arc blow, sometimes experienced with direct current welders, thus reducing the number of rejects to a considerable extent and avoiding the necessity of reworking welds.

150-AMPERE D.C. ARC WELDER

A new 150-ampere, direct-current, single-operator arc-welding equipment has been announced by General Electric which further extends its line into the field of light-gage work. The new equipment, because of its high, instantaneous recovery of voltage, prevents arc pop-outs at all points in its wide welding range with any good bare, lightly coated, or heavily coated electrode. Its stability prevents excessive current surges, thus avoiding excessive spatter loss and sticking of the electrode.

FLEXARC WELDING CABLE

A Flexarc Welding Cable, that is flexible, durable, light in weight and has positive insulation, applicable for field and shop use, is announced by Westinghouse Electric & Manufacturing Company. These cables comply in all respects with latest I.P.C.E.A. specifications for rubber sheathed arc-welding cables.

The paper separator between the copper and rubber sheathing, permits sliding action between the outside layer of wires and the rubber jacket. Also, the large number of fine copper wires composing the stranding provide for extreme flexibility. The protective jackets of these cables are of 60% rubber armor, built for hard usage under the most severe conditions and for long, reliable service with maximum safety.

CONTROL FOR POLYPHASE A. C. POWER

Illustrated is a continuously variable polyphase reactor which develops a drop of 300 volts at 50 amperes per coil.

This device should be generally useful in industry when it is necessary to have a smooth, continuous control of polyphase power.

PORTABLE MEDIUM-PRESSURE ACETYLENE GENERATOR

The Linde Air Products Company, Unit of Union Carbide and Carbon Corporation, has announced a new, portable acetylene generator, developed for the user of small quantities of acetylene for oxyacetylene welding and cutting.

This new generator, the Carbic Medium-Pressure Acetylene Generator utilizes the unique advantages of Carbic processed calcium carbide. Like all Carbic generators it makes available a dependable supply of acetylene, generated as required. It takes eight cakes of Carbic processed carbide at a single charge, and yields approximately 80 cu. ft. of acetylene from one charging.

The outstanding feature of the new generator is the rubber sealing cone which automatically seals off the cake holder from the water shell when the generator is not in use. This assures the most economical use of the charge of carbide, and prevents the generation of acetylene when it is not needed.

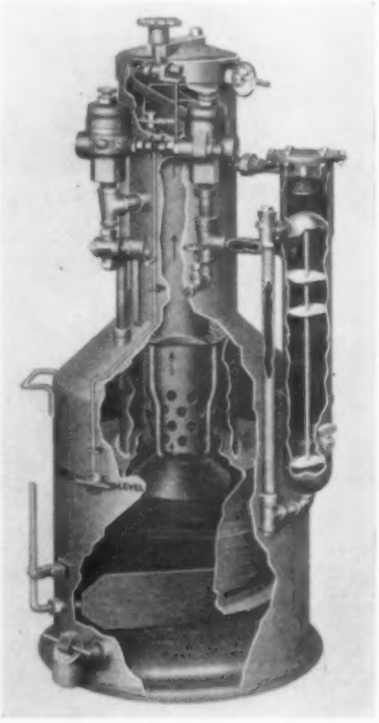


Fig. 1—New Medium-Pressure Acetylene Generator Embodies a Number of Improvements Heretofore Unavailable

WELDING SOCIETY AWARDS, MEDALS AND PRIZES

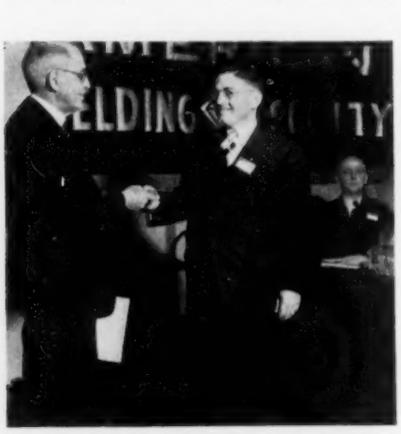
The Samuel Wylie Miller Memorial Medal, an annual award of the AMERICAN WELDING SOCIETY for conspicuous contributions to the advancement of the welding or cutting of metals was presented at the opening session of the 1938 Annual Meeting of the AMERICAN WELDING SOCIETY to J. W. Meadowcroft.

Dr. H. L. Whittemore, Chairman of the Board of Awards, presented the Medal to Mr. Meadowcroft for his pioneering work in the fabrication by welding of automobile bodies.

Joseph Walker Meadowcroft was born August 21, 1889, at Philadelphia, Pennsylvania. He is entirely self-educated, having started working at the age of eleven, and although still less than fifty years of age, more than thirty-five years of his life have been devoted to vigorous work, a description of which would constitute the story and the evolution of the all-steel automobile body. His remarkable memory and business perspective have made him invaluable in his executive position as Assistant Works Manager of the Edward G. Budd Manufacturing Company, Philadelphia, but he nevertheless finds time to keep in intelligent contact with the latest welding developments, to which he is still contributing.

In addition to the heavy managerial and executive duties which he has shouldered at home and abroad for the Budd Company, Mr. Meadowcroft, as an inventor, has contributed materially in a creative way to the advancement of the welding art. There have been issued to him some twenty-five or thirty U. S. patents and some fifty-four foreign patents.

In the long days before the advent of the portable electric welding tools, his patented multiple groupings of electrodes and shifting and adjustable electrodes for stationary welding machines greatly increased the speed of welding as done on stationary welding machines. So also did his patented jigs and fixtures for automobile subassemblies to be welded both by poke welding and stationary machines. He did considerable work on electrode clamps to facilitate quick adjustment. His patented flux for oxyacetylene welding is even today one of the very best. His



Prof. Whittemore Presenting the Samuel Wylie Miller Memorial Medal to J. W. Meadowcroft

"Joe" Meadowcroft Recipient of the Miller Medal

use of a "donkey" welder for making seams by a succession of overlapping spots was one of the very first. His patented process for indirect welding of the outer panels of doors of automobile bodies in a manner to avoid such marring by welding as would impair finish, has been of outstanding value and continues in use today.

Mr. Meadowcroft is a charter member of the AMERICAN WELDING SOCIETY, and served as Vice-President and Director of the National Organization as well as Chairman of its Philadelphia Section. He is also President of the Philadelphia Welding Club, and Chairman of the Welding Committee on Research, Budd Industries. He was formerly Director of the Welding Division Edward G. Budd Manufacturing Company. In 1930-31-33 and 34, he was Sous Director, American Mission, Citroen Motor Car Company, Paris, France, and in 1933, with Mr. Andre Citroen, was decorated by the Sultan of Morocco.

His immense vitality has not only produced numerous individual accomplishments, but has imbued his subordinates with a similar energy. He has written more than thirty papers on welding, seventeen of which have appeared in the Journal of the AMERICAN WELDING SOCIETY. These, as well as the numerous patents issued to him, have been mostly in connection with the welding of steel automobile bodies. In short, he has made original contributions toward the solution of every problem with which he has come in contact. His attitude toward advice has ever been receptive, his attitude toward progress, that of the pioneer. His associates in his every field of activity have felt the inspiration which comes from the forward-looking view which Mr. Meadowcroft has consistently expressed.

Lincoln Gold Medal

The second presentation of the J. F. Lincoln Award for the best paper representing original contribution to the advancement of the use of welding, was this year made in duplicate to co-authors of the prize-winning treatise, in Detroit on Monday, October 17th, at the opening session of the Annual Meeting of the AMERICAN WELDING SOCIETY.

Mr. G. T. Horton, President of the Chicago Bridge and Iron Works, and member of the Board of Awards presented the medals to J. C. Hodge and C. R. Sadler for their paper on "Weldability and Properties of Materials for Casing String."

James Campbell Hodge was born in 1902 at Falkirk, Scotland. In 1916 he came to America, completing his secondary education in Cleveland, Ohio. He received his B. S. degree from Case School of Applied Science in 1923, majoring in metallurgy under Professor H. M. Boylston.

For four years after graduation he was associated with Messrs. Bennett and Christensen, Consulting Chemists, serving a number of foundries in Ohio and Indiana.

In 1927 he joined the Babcock and Wilcox Company to investigate the status of the various welding processes and to develop a process of welding suitable for application to the construction of boiler drums.

His experimental work during this period contributed to a better understanding of the behavior of steel in metal arc welding and of the functions of coverings on electrodes in producing ductile metal arc-weld metal. He was associated with Professor H. F. Moore in the classical experiments of the Babcock and Wilcox Company, involving fatigue tests on full sized drums and shells of riveted and welded construction. His investigations of methods of non-destructively testing welded joints are also well known, and he became a recognized authority in this field. The wide spread use of industrial radiographic examination is largely based on the success of these early investigations.

During this period he developed and perfected the process of welding, utilized by this company for the welding of boiler

George T. Horton Presenting the Lincoln Gold Medal and Certificate to Dr. J. C. Hodge, Co-Author of the Winning Prize Paper

Mr. Sadler, Recipient of the Lincoln Gold Medal and Certificate as Co-Author of Paper on "Weldability and Properties of Materials for Casing String."

drums and the welding of other important constructions such as the power penstock piping of the Boulder Dam project.

Between 1931 and 1933 he continued his metallurgical studies at Harvard University, his doctorate being obtained under Professor Albert Sauveur—the dean of American metallurgists.

His later work has included studies on the weldability of the low-alloy constructional steels and of the various heat resistant and corrosion resistant steels, in the metallurgy of which he has also gained a considerable reputation.

Dr. Hodge has cooperated in the activities of many of the engineering societies, serving on a number of the technical committees of the American Society for Testing Materials, the Boiler Code Committee of the A. S. M. E., the Welding Research Committee of The Engineering Foundation, the AMERICAN WELDING SOCIETY and the American Petroleum Institute.

He has made many contributions to the technical literature on welding, being co-author of two chapters of the Welding Handbook of the AMERICAN WELDING SOCIETY.

Cornelius Robinson Sadler was born in Montgomery, Alabama in 1875. In his early youth he took an apprentice course as a mechanic, following which he spent several years at various mechanical jobs in the South. In 1901 he came north and shortly thereafter made a connection with the Stirling Boiler Company, later The Babcock & Wilcox Company at Barberton, Ohio, and has been with this concern ever since, serving in various capacities, and is now Vice-President of The Babcock & Wilcox Tube Company at Beaver Falls, Penna. During this period Mr. Sadler has been active in the development, design and manufacture of such apparatus as steam boilers and their auxiliaries for land and marine service, and the designing and building of machinery for manufacturing same.

Just prior to the entrance of the United States in the World War he was directly responsible for the forging of a large quantity of 9.2 shells for the Allies.

During the last years of the use of riveted construction for pressure vessels, Mr. Sadler developed the technique of manufacturing a higher grade riveted joint than had previously existed, which made it possible to use riveted joints for thicker plates and higher pressures than had previously been used.

Upon the introduction of fusion and resistance welding, Mr. Sadler recognized its possibilities for replacing the various types of mechanical joints previously used in pressure vessels, tubular goods, etc., and took steps for the development of improved welding technique as well as non-destructive testing of welded structures.

During recent years Mr. Sadler has devoted his time to the development and manufacture of tubular goods at the Beaver Falls plant of The Babcock & Wilcox Tube Company. Through his many visits to the oil fields he became interested in their problems of welding applications, resulting in his investigation of casing welding as reported in a joint paper with Dr. J. C. Hodge dated March 4, 1938: "Weldability and Properties of Materials for Casing Strings."

The practice of welding the joints of casing as it is run into the well is being adopted because of the substantial saving which can be realized in the cost of pipe strings, the increased joint strength which makes possible the safe running of longer strings, the greatly reduced possibility of leaks; and the more complete recovery of pipe on abandoned wells since with welded joints there are no projections to hinder pulling the pipe.

Touching briefly upon the history of welding applied to casing work, the study discusses: specifications, physical properties and manufacture of casing pipe; conditions to which casing pipe is subjected in drilling operations; influence of compression yield point on the collapse resistance of casings; effects of alloying elements on the strength of steel; welding of casing strings and requirements of welded joint; weldability of standard and high yield casing steels; electrodes and weld metal for this type of work; tests, explained and illustrated, of welded casing joints for weld penetration, deformation, bend, crushing, tension and impact.

The paper makes a prediction of increasing use of welding in stringing casing pipe within the next two years.

Industry and Welding Prize

The *Industry and Welding* prize which was awarded for the winning graduating thesis of Senior Students in land grant colleges was won by Mr. G. R. Maples, Jr., Alabama Polytechnic Institute.

Mr. Maples' thesis covered the subject of "Student Projects, in the College Welding Laboratory."

This award was designed to attract Senior engineering students to welding as a field for their life's endeavors.

There were two divisions in the award—one for the best gas paper and one for the best electric paper but, inasmuch as the notice of the awards was made so late in 1938, no one qualified in the electric classification. However, Mr. Maples' paper was well done and is attracting much attention.

EDUCATIONAL LECTURE COURSE CHICAGO SECTION, WINTER SESSION 1938-39

Sixteen lectures are to be presented by the Chicago Section in this series. The lectures will be held in the new Student's Union Building of Armour Institute of Technology, 33rd & Federal Street. The tentative program is as follows:

December 5th—K. L. Hansen, Consulting Electrical Engineer, "Arc Welding Phenomena and Equipment."

December 12th—W. B. Browning, Process Service Engineer, The Linde Air Products Co., "Fundamentals and Applications of Oxyacetylene Welding and Cutting."

December 19th—H. A. Woofter, Consulting and Designing Resistance Welding Engineer, "Spot Welding Equipment."

December 20th—E. W. Forkner, Chief Engineer, Federal Machine and Welder Company, "The Importance of Resistance Welding."

January 9th—Dr. W. A. Pearl, Department of Mechanical Engineering, Armour Institute of Technology, "Metallurgy and Heat Treatment Involved in Welding."

January 16th—H. C. Boardman, Research Engineer, Chicago Bridge & Iron Co., "Welded Elevated Tanks."

January 23rd—W. D. Halsey, Assistant Chief Engineer, Boiler Division, Hartford Steam Boiler Insp. & Ins. Co., "Inspection of Welds and Methods of Testing."

January 24th—R. B. Lincoln, Director of National Weld Testing Bureau, "Inspection of Welded Structures and Testing of Welding Process and Operators."

January 30th—F. H. Dill, Welding Engineer in the Mechanical Engineering Dept., American Bridge Company, "Structural Steel Welding—Bridges, Buildings."

February 6th—E. J. Brady, Welding Engineer, Hollup Corporation, "Welding Technique and Applications in the Field of Stainless Steels and Stainless Irons."

February 13th—A. J. Moses, General Manager, Hedges Walsh Weidner Division, Combustion Engineering Company, "Welding of Pressure Vessels."

February 14th—L. J. Larson, Consulting Welding Engineer, "Welding of Pressure Vessels for the Petroleum Industry."

February 20th—A. E. Gibson, President, Wellman Engineering Company, "Designing and Welding Large Machines."

February 21st—Everett Chapman, President, Lukenweld Incorporated, "Designing and Welding Large Machine Tool Structures."

February 27th, February 28th, March 6th—E. A. Balsley, Welding Engineer, Link Belt Company, "Use of Welding in Maintenance." Use of Arc and Gas Welding, also Gas Cutting in General Shop and Field Maintenance Work.

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Sponsored by the American Welding Society
and American Institute of Electrical Engineers

Supplement to the Journal of the American Welding Society, November 1938

The Influence of Residual Stress on the Strength of Welded Seams*

By J. P. DEN HARTOG† and O. E. RODGERS†

SUMMARY

A METHOD is described for producing an internal stress distribution in plates similar to that found in welded plates *without* changing the metallurgical structure of the plates. By this method the effect of internal stresses on strength properties can be evaluated without any disturbing effect from the metallurgical changes consequent upon the welding process. The plates were subjected to destructive tensile tests in a direction parallel as well as perpendicular to the direction of the internal stresses. No change was found in the strength properties of the plates with and without these internal stresses. This indicates that the cracks experienced in welded structures of ductile boiler plate subjected to slowly varying stress are *not* due to internal stresses, but must be a result of the metallurgical modifications of the material.

INTRODUCTION

At the present time a standard procedure in the manufacture of welded pressure vessels is a stress anneal after fabrication, which is rather costly when the vessels are of more than moderate size. Although the A. S. M. E. Unfired Pressure Vessel Code requires such a stress anneal in most cases, there is very little experimental evidence available which tends to shed any light on the effect of internal stresses by themselves on the strength properties of welded structures.

The distribution of stress around butt-welded joints has been thoroughly investigated.[1] It is characterized by a very high tensile stress in the direction of the weld and smaller compressive stresses in the same direction farther removed from the bead. In a seam of a foot or more in length, these are the only stresses of any importance, the conditions at the ends of the bead being of a local character.

A steady tension or compression in the direction of these stresses should not produce any surprising results, since the uniform straining should even out the stresses after a very small amount of additional imposed strain. This has been found to be the case by Lance Martin.[2] When the applied external stresses and the internal tension are at right angles to each other, there is reason for believing that some change in the strength properties might take place, since in the region of the weld there are two principal stresses at right angles to each other. It has been found experimentally that such a condition tends to make the material more brittle and tends to produce a higher strength at failure.[3] The tests described in this paper were made to determine experimentally what effect this condition might have.

METHOD

It was first necessary to devise a method for producing an internal stress distribution similar to that found in welded plates without changing the metallurgical structure of the plates, so that any effect found could be attributed solely to internal stresses. This was accomplished by running a bead on a strip of steel about one quarter of an inch thick which had been clamped over the plates to be treated. The arc did not penetrate to the plates below, but the temperature below was raised high enough to cause the metal to reach its yield point in compression and produce internal tension after cooling again to room temperature. The strip naturally does not fuse with the plate and is lifted off after the welding. Beyond a little cracked scale no surface effects are discernible on the treated plate. For mild steel of the strength used in these tests, an increase in temperature of 150° F. would cause a rigidly held piece to become plastic. A temperature difference of slightly more than twice this value will cause sufficient permanent set to create after cooling of the restraining material on each side of the heated strip a tensile residual stress equal to

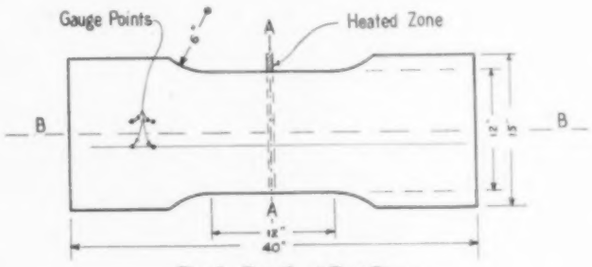


Fig. 1—Details of Test Piece

* The research described in this paper was carried out under a grant from the Milton Fund of Harvard University, and with the use of the testing facilities of the Watertown Arsenal by kind permission of the Commanding Officer, Col. G. F. Jenks, and later Col. R. W. Case. Contribution to Welding Research Committee.

† Harvard University.

[1] See Research Supplement to AMERICAN WELDING SOCIETY JOURNAL, Nov. 1937.

[2] H. E. Lance Martin, Inst. of Welding Trans., I No. 1, pp. 35–51 (Jan. 1938).

[3] E. Siebel and A. Maier, Z. *VDI.*, **77** No. 51, pp. 1345–1349 (1933).

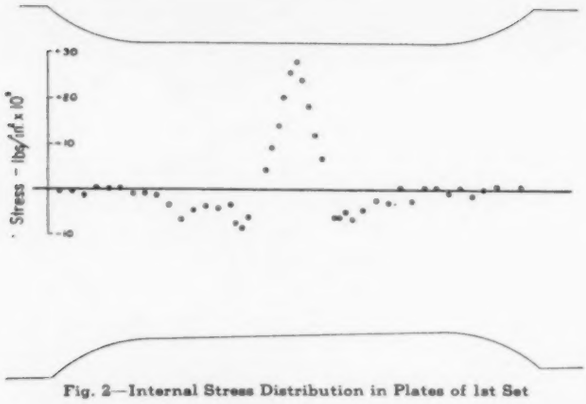


Fig. 2—Internal Stress Distribution in Plates of 1st Set

the yield stress. Thus, the maximum temperature necessary to produce such an internal stress distribution is well below 500° F., which is considerably less than the temperature at which changes in metallurgical structure begin to take place. In order to make sure that the rest of the plate remained at room temperature, the specimens used were water cooled on both sides of the bead during the welding operation. The welding was done with an automatic machine, so that the process could be repeated under the same conditions.

After the specimens had been treated in this way, one from each set was cut up to determine the actual stress distribution. At the same time, sections were made of different portions for microscopic examination. The micro structure of the heated portion remained unchanged except for a small strip about 0.05 inches wide and half as deep, just under the bead in some of the plates. In this insignificant region the carbon content was raised probably by a coating of oil on the cover strip. Hardness tests over the portion which had been heated showed only a slight increase over those over the untreated portions, the average values being 80 Rockwell "B" for the former and 78 Rockwell "B" for the latter. As a final test, a tensile test specimen $^3/_8$ inch in diameter was made from the heated zone of a plate and compared with one cut from the untreated portion of the same plate. The yield point had increased from 40,000 pounds per square inch to 41,200 pounds per square inch, an increase of 3%.

It, therefore, seems safe to conclude that the heating procedure produces no change in the metallurgical structure.

EXPERIMENTAL RESULTS

Two sets of tests were made, using test pieces of commercial boiler plate $^1/_2$ inch thick of the form shown in Fig. 1, all the pieces in each set being cut from the same rolled sheet with the same direction of rolling. The test pieces of each set were machined together so that they were identical in shape. After machining, they were stress annealed at 600° C. for twelve hours to remove rolling and machine stresses.

The first set consisted of three plates, two of which were heated along the center line (line *A–A* in the figure) by the method described in the previous section, first on the upper side and then in the reverse direction on the under side, the intention being to eliminate unsymmetrical effects caused by the slow motion of the heating spot across the plate. For each weld, the voltage drop across the arc was about 26 volts, the welding current about 380 amperes, and the welding speed nine inches per minute. The plates were assumed to be identical as far as stress distribution was concerned. The justification of this assumption is illustrated by the similarity of the two internal stress curves plotted in Fig. 3.

The internal stresses set up in one of the heated plates were determined in great detail by measuring very accurately the distance between pairs of holes drilled 2.5 inches apart at various points on both surfaces of the plates with an especially accurate Berry type strain gage. Comparison readings were taken between a standard set of holes and the pair to be measured, because the gage was found to be too sensitive to make absolute measurements possible. About 160 pairs of gage points were drilled on each side of the plate, some of which were arranged at the corners of triangles so that three measurements were possible from three points. The plate was then cut into small pieces to relax all the stresses set up by the welding treatment and the distances between the pairs of holes measured again. The relaxation strains thus measured are a measure of the internal stress conditions in the plate.

The main character of the strain pattern thus found consists of a tensile strain almost equal to the yield point in the heated zone and balanced by areas of lower compressive strains on both sides of the heated zone, the direction of both being parallel to the heated line. Secondary compressive strains of about one quarter of the yield strain in tension were found at the ends of the weld perpendicular to the heated zone with a balancing region of very low tensile strain in the center.

A plot of the relaxation strains measured between pairs of holes drilled parallel to line *A–A* at intervals along line *B–B* is shown in Fig. 2. Because of the very small magnitude of the other strains measured, these strains may be transformed directly into stresses, using a value of Young's modulus of 30,000,000 pounds per square inch. It is seen that the stress in the very middle section is roughly the yield point of the material in tension, as found from the tests of the large test pieces.

The two remaining plates of the first set (one without any stress, the other with the stresses of Fig. 2) were tested in the Emery testing machine at the Watertown Arsenal, and stress-strain curves obtained which showed the entire plastic yielding until fracture. The curves were found to be identical for the two plates:

	Stressed Plate	Stress-Relieved Plate
Yield point (lb. per sq. in.)	34,300	35,500
Ultimate strength (lb. per sq. in.)	59,000	57,500
% Reduction in width	18.3	19.2
% Reduction in thickness (at center)	36	38
Total elongation (in.)	5.2	5.3

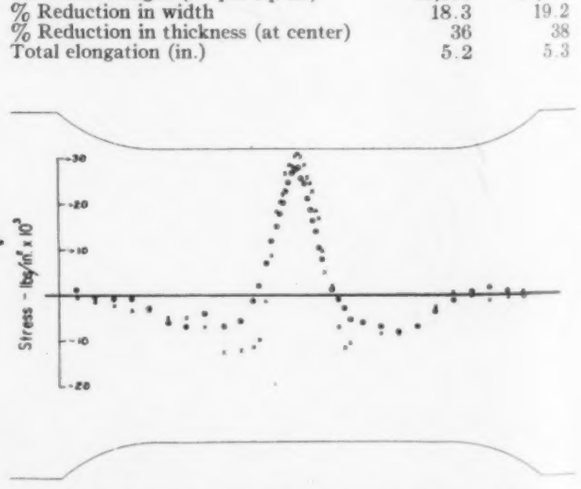


Fig. 3—Internal Stress Distribution in Plates of 2nd Set
o—Plate loaded to 150,000 lb.
x—Unloaded plate

The fracture occurred in the exact center in the case of the stress-relieved plate, while in the other it was about two inches to one side of the heated zone.

The second set consisted of four plates, three of which were heated in the manner described above, the only difference being that the welds were made at the slower speed of eight inches per minute. One of these three was used to determine the internal stress distribution and the strains obtained along line *B–B* are plotted as small crosses in Fig. 3. Since another complete survey was not necessary, the only gage points measured were 71 pairs of holes distributed along lines *B–B* on each side of the plate.

The unstressed plate and one of the two stressed plates were tested to destruction in the same manner as before and again the resulting stress-strain curves were practically identical, as follows:

	Stressed Plate	Unstressed Plate
Yield point (lbs. per sq. in.)	31,000	32,500
Ultimate strength (lbs. per sq. in.)	60,200	60,500
% Reduction in width	16.7	17.5
% Reduction in thickness (at center)	26.5	37.5
Total elongation (inches)	4.75	4.6

The third plate with internal stresses was subjected to a load of 150,000 pounds, i.e. to 82% of the yield stress, and then cut up to determine whether or not the internal stress distribution had been materially altered. The strain measurements along line *B–B* were found to agree with those found previously (small circles in Fig. 3). This test was carried out to ascertain whether or not the internal stresses would be relieved by the application of a large stress in a perpendicular direction. Since they are not, it can be concluded that all plates reached their yield points in the testing machine with their residual stress patterns completely intact, and that thereafter, in spite of the internal stresses, they were just as ductile as if they had been stress annealed.

CONCLUSION

These results indicate that the internal stress system in the vicinity of a welded joint has no effect on the slow tensile strength properties of the joint. The stresses found show that the center section of the plates was subjected to tensile stresses as high as the yield point in two perpendicular directions, which, however, made no difference in the behavior of the metal in plastic flow.

It follows that *stress annealing is not necessary for structures which are subjected to unvarying or slowly varying stresses.* Naturally, the tests do not give any information on the behavior of unannealed welded structures subjected to fatigue or impact stresses, and further research in this direction is in order.

The authors wish to express their appreciation to Professor C. A. Adams for suggesting the subject of this research and to Major J. L. Guion, Dr. H. H. Lester, Mr. W. L. Warner and Mr. H. C. Mann of the Watertown Arsenal for the generous loan of time and equipment.

Discussion by Dr. Comfort A. Adams of the Paper on "The Influence of Residual Stress on the Strength of Welded Seams" by J. P. Den Hartog and O. E. Rodgers, Harvard University

The authors are to be congratulated on developing a new and novel method of studying the matter of internal stresses in welded joints. This problem, as every one knows, is extremely important and difficult of exact quantitative analysis. Owing to the microstructure of the weld-metal in the affected zone, it is appreciably stronger and has a higher yield point than the base metal. Thus, under stress the first yield occurs in the ductile base metal, after which the stresses are so distributed that the overall strength is unaffected by the presence of the original residual stresses. In other words, if no cracking occurs before the weld is thoroughly cooled, assuming it is mild steel, it is quite unlikely that any failure should occur due to residual stresses. In fact, this is thoroughly proved by many years of experience on thousands of structures of this material.

However, a little analysis will show that if the stress gradient is steep enough to produce vigorous multi-axial stresses, failure will occur when the stress in the weld zone reaches its ultimate strength, which may be long before the overall stresses have reached that point, of course only under the specified conditions.

Fortunately, the specified conditions of very steep stress gradients are very exceptional. Moreover, the overall stress may never reach this critical point.

It is generally agreed by all of those close to this problem that under static or slowly changing stresses, there is little need to worry about the residual stresses set up by the welding of mild steel. But this does not apply to alternating, pulsating or impact stresses.

The original objective which I had in view was to establish, if possible, some quantitative connection between the stress gradient (or the factors which cause it) and the resultant strength of the weld under the three major types of stress, or in general, to supply information sufficient to indicate for what types of service, for what thicknesses of material, and for what materials, stress relieving is necessary for safety.

I realize fully that this is a big contract, but it is certainly a job worthy of our best efforts.

The authors point out correctly that the residual stresses cannot exceed the yield point in any case except where the stress gradient is so steep, or the restriction to the flow of metal is so great as to result in bi-axial, or tri-axial stresses; the amount of the plastic yield is generally much greater in an actual weld than indicated in the experiments of the authors. Moreover, the cracks to which the authors refer in the last sentence of the Summary are unquestionably due to the cooling stresses, in spite of the fact that they might not have occurred with those same cooling stresses, if the microstructure had remained unchanged. As a matter of fact, the changes in the microstructure of a mild steel plate due to welding, usually involve an increase in volume and not a decrease, so that the stresses which cause the cracks are thermal in origin, although the

cracks might not have occurred in the more ductile condition of the original plate material.

If I interpret Fig. 1 correctly, the test stress was in every case perpendicular to the heat-effected line, whereas the test curves are transverse stress plotted longitudinally. It is obvious that there can be no overall longitudinal stress across the heated zone, although there may be some ups and downs from one side to the other.

In other words, test stress in these experiments was perpendicular to the major residual stress, and there seems to be no reason to expect any result other than that which was obtained. However, even if the test stress had been applied along the line of the heat zone, there would have been no reason to expect any different result, since the stress gradient was not steep enough to produce the brittle fracture which occurs with large enough bi-axial stresses.

There is another very important variable which does not enter into these experiments, but does enter in the case of much thicker plates, namely, the accumulated shrinkage stress due to the deposit of many layers of weld-metal in a joint between heavy plates. It is practically impossible to make such welds without the peening of every layer or two of weld-metal. Otherwise, the surface of the plate will actually crack outside of the weld zone or near to it before the weld is finished.

THE DETERMINATION OF INTERNAL Stresses from the Temperature History of a Butt-Welded Plate*

By O. E. RODGERS† and J. R. FETCHER†

SUMMARY

THE internal stress distribution to be expected in two plates, butt-welded together by the thermit process, is calculated from the experimental record of the variation with time of the temperature over the surface of the plate. This stress distribution is found to be in good agreement with the internal stresses measured by the relaxation method.

INTRODUCTION

The difficulty of predicting the nature and magnitude of residual weld stresses for a given structure and procedure is a deterrent to the progress of the welding art. For any cases the stresses can be measured experimentally with fair accuracy, but it is not possible to alter the conditions and predict the resulting change in the internal stresses. Costly and time-consuming experimental tests on models or full-scale structures have been the only means for investigating new types of welded structures.

The method described in this paper furnishes a means of predicting the internal stress distribution in flat, butt-welded plates from a record of the temperature variations in time and space. These variations were both calculated and measured and found to be in good agreement. The problem was simplified by assuming in the theoretical work that all the weld-metal was deposited at one time; the experimental welds were made by the thermit process in order to approach this condition as closely as possible. Although this condition is far from ordinary welding practice, the stress pattern obtained is strikingly similar to that found when two plates are arc welded together in the ordinary manner. The analysis of this idealized problem furnishes a quantitative insight into the relationship between thermal and stress patterns which is valuable in the study of more complex problems.

* The research described in this paper was carried out under a grant to Professors Adams, Den Hartog and Sauveur from the Milton Fund of Harvard University. A contribution to the Welding Research Committee.

† Harvard University.

EXPERIMENTAL WORK

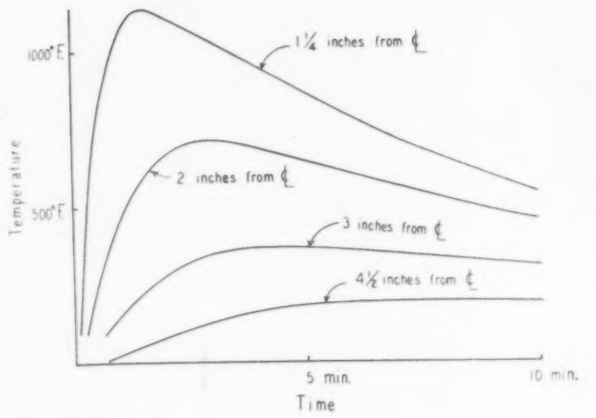
Two similar thermit welds were made, the first allowing an accurate determination of the residual stress to be made, and the second furnishing a temperature record.

The welds were made along the long edges of two $^3/_4$ inch thick mild steel (0.20% carbon) plates measuring 15 inches by 30 inches, which had been bolted in a vertical position in a rigid framework so that the edges were one inch apart. A mold of a refractory material was built up around the joint to provide a somewhat circular cross section for the molten metal. The thermit apparatus was placed directly over the mold. This vertical arrangement permitted the thermit metal to be poured in the shortest time but had the disadvantage that the first portion of the stream had cooled somewhat by the time it reached the bottom of the mold. A temperature record was obtained by inserting four chromel-alumel thermocouples at distances of $1^1/_4$, 2, 3 and $4^1/_2$ inches from the center line of the weld in the center section of the plate. These were connected to four sensitive milli-voltmeters which had been placed so that a motion picture camera, driven by a synchronous motor, could be focused on them. The camera film thus contained a record of the thermocouple voltages which could be translated into temperature readings after calibration. Automatic temperature recorders were found to have too great a time lag.

In both cases, the weld metal itself was quite porous, but the fusion between the weld metal and the plates was good. No temperature record was obtained during the first weld because an overflow of weld metal short-circuited the thermocouples. The temperature records obtained during the second weld are shown in Fig. 1.

The internal stress distribution in both plates was determined by measuring the relaxation strain with an especially sensitive Berry type strain gage. The distance between gage holes was $2^1/_2$ inches. While the excess weld metal on the second plate was being planed off, a long crack appeared in the weld, owing to its extremely porous nature. Therefore, since the moment

Fig. 1—Measured Temperature History of Four Points on the Second Plate



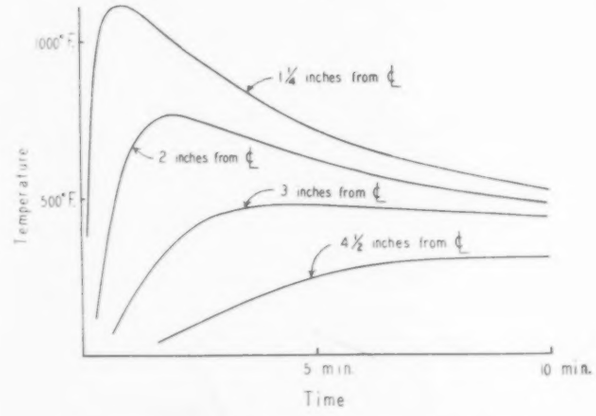


Fig. 2—Calculated Temperature History of Four Points

action of the unbalanced stress system on each side of the weld had been allowed partially to take effect, the strains measured in the second plate did not indicate accurately the internal stress distribution. The stresses measured in the first plate should be a true measure of the internal stress situation arising from the welding procedure used (see Fig. 5). The tensile stress in the center is seen to reach a value of 33,000 pounds per square inch, which is very close to the yield point of 35,000 pounds per square inch found for standard $^1/_2$ inch diameter test specimens cut from the plates.

TEMPERATURE CALCULATIONS

In calculating the temperatures to be expected over the surface of the plates, it is assumed that all the weld-metal was poured and in place before the temperature of the base metal on either side was raised appreciably. The refractory mold which extended 4 inches from the center line of the weld insulated the plates to such an extent that radiation may be neglected. The framework bolted to the outer edges of the plates is assumed to be a continuation of the plates. Then, the problem is reduced to that of finding the temperature history of an infinite plate, the initial conditions being that all of the plate is at room temperature except the heated strip, in which the temperature is that of the molten thermit metal, about 5000° F. End effects are neglected and a flow of heat is assumed only perpendicular to the weld.

The solution of the problem is given by Byerly[1] and is

$$T = \frac{T_m}{\sqrt{\pi}} \int_{\beta_1}^{\beta_2} e^{-\beta^2} d\beta;\ \beta_1 = \frac{-b-x}{2a\sqrt{t}},\ \beta_2 = \frac{+b-x}{2a\sqrt{t}}$$

when the y-axis is taken through the center of the heated strip, and

T = temperature at distance x at time t
T_m = initial temperature of heated strip above room temperature
b = half width of heated strip
$a = \sqrt{\frac{k}{\rho c}}$
k = thermal conductivity
c = specific heat
ρ = density

T_m was assumed to be 4900° F. above room temperature, which was taken as zero. Mean values of the constants were used and no provision was made for variation with temperature. The values used were:

$k = 6.48 \times 10^{-4}$ B. t. u./in./° F./sec.
$c = 0.16$ B. t. u./lb./° F.
$\rho = 0.28$ lb./in.^{3}

Assuming that none of the excess weld-metal was effective in raising the temperature of the plates, the value of the width of the heated zone to be used in the calculations is the distance between the plates, or 1.0 inch. On the other hand, if it is assumed that the heat energy of all the weld-metal deposited is transmitted to the plates, the value for the width of the heated zone must be increased. Since Byerly's solution applies only to a plate of uniform thickness, the total volume of weld-metal must be assumed to be deposited in a strip $^3/_4$ inch thick. The width of this strip was calculated to be 1.5 inches. Thus, the value of the half width (b) to be used must lie between 0.5 and 0.75 inches, or about 0.6, the value used (see Figs. 1 and 2).

[1] Byerly, "Fourier's Series and Spherical Harmonics," page 83, No. 4.

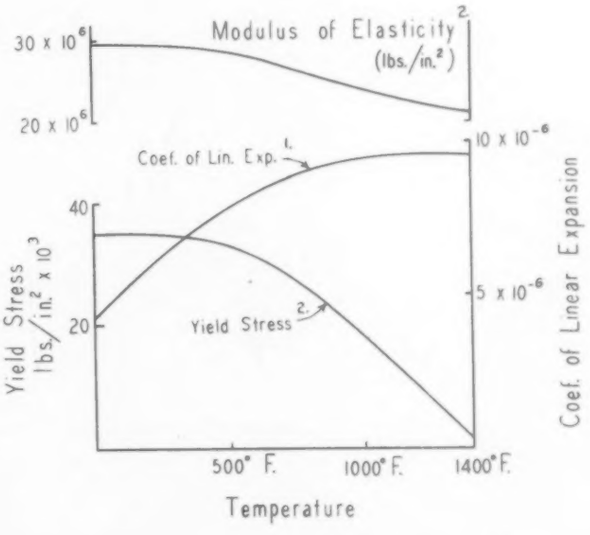


Fig. 3—Approximate Variation with Temperature of Some Physical Properties of Mild Steel

[1] From "Metals Handbook" 1936.
[2] Adapted from S. Timoshenko, "Strength of Materials", **2**, p. 699 (1930); and Boulton, N. S., and Lance Martin, H. E., *Proc. I. Mech. E.*, **133**, pp. 295–339 (1936).

The measured temperature curves fall off more rapidly for the points farthest from the weld because of radiation beyond the mold. Except for this difference, the two sets of curves are in close agreement.

STRESS CALCULATIONS

In order to obtain a solution for the internal stress system resulting from the temperature variations, it is necessary to assume that the plate is long in the direction of the weld and to consider only cross sections of the plate far enough from the ends so that end effects play no part. The material is assumed to be perfectly elastic up to the yield point and to be capable of indefinite extension beyond the yield point with no increase in the stress required.

The solution for the temperature stresses in the central portion of a long flat plate of width (w) in which the temperature varies only across the plate [$T = T(x)$] and is symmetrical with respect to the center line of the plate is known for the case in which Young's modulus (E) and the coefficient of thermal expansion (α) do not vary with temperature. The only stress is a stress in the y-direction consisting of a compressive stress equal to [$E\alpha T(x)$] plus a uniform tension equal to

$$\frac{1}{w}\int_{-\frac{w}{2}}^{+\frac{w}{2}} E\alpha T(x)dx$$

so that the resultant of the normal forces over any section will be equal to zero.

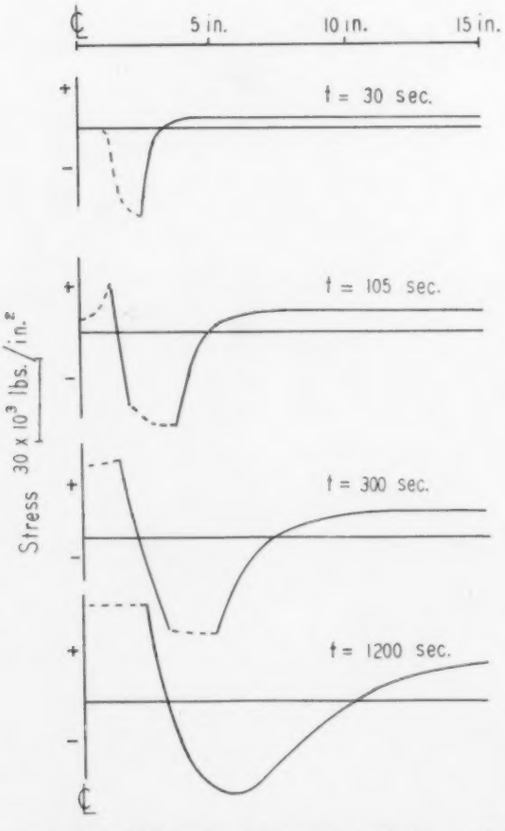
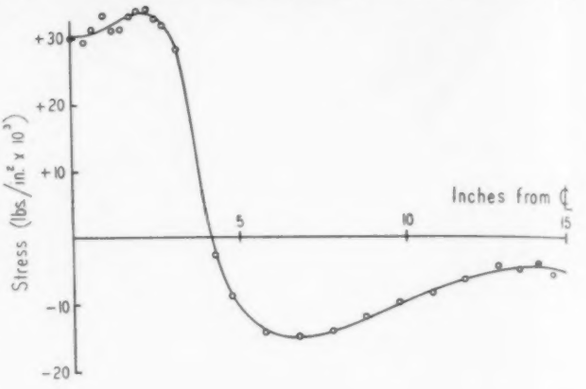


Fig. 4—Internal Stress Distribution During Cooling at 30, 105, 300 and 1200 Seconds After Welding
– – – indicates yield stress

Fig. 5—The Measured Internal Stress Distribution in the First Plate



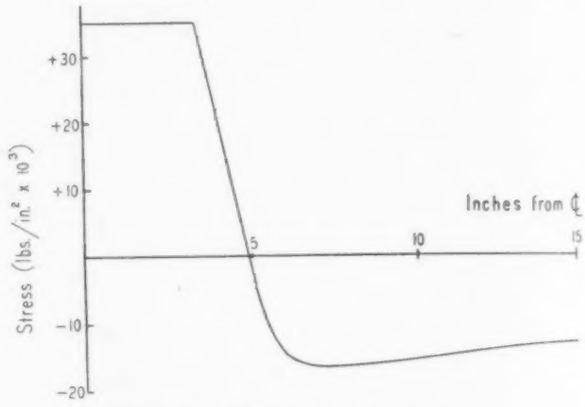


Fig. 6—The Calculated Stress Distribution

In the present case the temperature range is so great that variations in E and α with temperature cannot be neglected. The method employed is a step-by-step graphical integration, using small enough time intervals so that values of the yield stress, E, and α at a particular point can be considered to be constant during that time interval. At the end of each interval, the thermal stress is determined and superposed on the previous stress distribution and the system brought into equilibrium by superposing a force due to uniform straining of the material, the assumption being that plane cross sections remain plane. The stress at any point is never allowed to exceed the yield stress determined by the temperature of the plate for that point.

When the temperature of the center section is above 1200° F. that section should exhibit no elastic properties and the plates should still be completely separate as far as stress purposes are concerned. Thus, at first, there is a moment action of the normal forces tending to push the ends of the plate away from each other and tending to rotate the position of the stress zero line. However, the total moment of the stress system on one side of the weld when the weld-metal begins to become elastic would produce a relatively small rotation in a plate of this great a width. This effect is entirely neglected, in order to keep the problem one-dimensional.

The temperature distribution across the plate was calculated at several time intervals after the weld-metal was poured and the values of the temperature changes found at various points during the intervals. These were transformed into stress units using the values of E and α corresponding to the mean temperature of each point during each interval. Shown in Fig. 3 are the

curves used for the variation of E and α with temperature. The temperature changes were plotted in stress units on graph paper, on which also was plotted the yield stress corresponding to the mean temperature at each point during that time interval. The yield stress curve formed an envelope, inside of which all elastic action occurred. Figure 3 shows the assumed variation of yield stress with temperature. A graphical integration determined the force unbalance due to the temperature stresses.

In order to satisfy equilibrium conditions, it is necessary to superpose a force, derived from uniform straining of the plate. This superposition can be valid only if the variation of the modulus of elasticity across the section is taken into account. The stresses resulting from a uniform straining of the plate vary directly with the values of E. At each time interval the net force resulting from a unit strain was determined by graphical integration of the values of E across the section, considering only those areas which were not being plastically strained beyond the yield point. The uniform strain necessary to produce equilibrium was that fraction of unit strain which made the force from uniform straining equal to the force unbalance derived from the temperature changes during the interval. After superposing the stress system due to the straining, all conditions were satisfied, and the process was repeated for the next time interval. This was done for 37 intervals between zero and infinite time. The resulting curves contain a history of the stress changes during the cooling process (see Fig. 4). Yielding under compression is seen to occur as far as 6 inches from the center of the welded area.

The final stress distribution shown in Fig. 6 consists of a region of yield stress in the center and balancing areas of compression extending in to about 5 inches from the center line. This is in good agreement with the stress distribution measured in the first plate.

The stress gradient to be expected is seen to depend directly on the cooling rate which exists at a time 3 or 4 minutes after the welding. This suggests that diffused heating 3 or 4 minutes after welding of the area immediately surrounding the weld could materially reduce the stress gradient, although it could not reduce the high value of the stress at the center.

It was the interest of Professor C. A. Adams in the relationship between thermal and stress gradients resulting from welding and their effect on the strength properties of welded structures which gave this work its impetus and initial direction. The theoretical approach was suggested by Professor J. P. Den Hartog. The experimental work was done at the plant of the Metal & Thermit Corporation, who kindly donated the necessary facilities.

Discussion of Paper on "Arc Welding Atmospheres"*

By C. G. SUITS†

I AM GLAD to see that the authors separate the problem of penetration from that of crater formation. It has always seemed to me that there was no evidence that suggested any causal relationship between the two, and the experiments on nitrogen bear that out. The authors' view of the crater formation as an essentially mechanical problem seems reasonable to me.

If we now view the results on penetration separately, we find that in no case of welding in an atmosphere of nominally pure atomic gas is penetration observed; or, conversely, in all cases where penetration is found, the atmosphere contains a substantial amount of a diatomic gas. Thus, you find no penetration in A and He, and you do find penetration in N_2, O_2, CO_2 and H_2. It seems to me that this result is strong evidence that the dissociation-diffusion-recombination heat transfer process is of prime importance to penetration. The results with H_2 are not entirely conclusive in this respect, possibly for secondary reasons.

In going through the work which was reported by Alexander in the G. E. Review, 1926, I found that he observed good penetration and fusion and satisfactory quality of weld-metal with H_2. On the other hand, the metallurgical part of his work does not appear to have been done too comprehensively.

The measurements on hydrogen described in the paper with Bounds were not taken at exactly the same arc energy as in the case of the experiments with A, He, N_2, O_2 and CO_2. The porosity and bubbling which was found in the H_2 welds may be a result of the abnormally high heat transfer in that gas, causing boiling of the metal. It is clear that at some rate of energy input to the surface of the weld-metal this boiling must necessarily take place. In the case of H_2 it takes place with currents which show no boiling in other common gases, because in these gases the heat transfer is much smaller.

It is true that in welding in air the same porosity and boiling are found at very high currents. This seems to be the chief limitation to an increase in current as a means of increasing the rate of welding. If further experiments bear this out, we will have to conclude that fusion welding in H_2 at atmospheric pressure results in a rate of heat transfer that is too great.

There are several solutions for the problem, but it seems that the atomic hydrogen torch may be the most practical, because in this case the rate of heat transfer is controlled by the position of the torch. If the flame is held too close to the weld-metal, the same undesirable boiling which the authors have noted takes place. The other way of reducing the heat transfer in H_2 would be to weld in a hydrogen atmosphere at reduced pressure. This might fit in with the experimental program and would be worth while doing. Similarly, a higher rate of heat transfer and surface boiling at these same currents would be obtained with the common gases, for example, N_2, at some higher pressure. In the case of N_2 pressure of about 100 atmospheres would be required to duplicate the results of H_2 at 1 atmosphere; or the comparison of N_2 at 1 atmosphere might be made with H_2 at a pressure of about 1 cm. of Hg.

* Paper by G. E. Doan and A. M. Bounds published in June 1938 issue of Research Supplement.

† Research Laboratory, General Electric Company, Schenectady, N. Y.

EFFECT of ECCENTRICITY on the Strength of Welded Joints*

By WILLIAM W. STECKER†

THE problem of design for welding is a very complex one due to the large number of variables which must be considered. These variables may be classified into two general groups: those affecting the inherent properties of the weld-metal and those resulting from the shape and arrangement of the joint. In this paper it is proposed to study the effect of eccentricity on the strength and reliability of fillet-welded joints.

DESIGN OF SPECIMENS

Type of Joints

Five different types of joints were selected from the many types available. These joints are commonly used in structural work and they show very well the effect of symmetry on the strength of the joint. In all of these joints the welds were symmetrical with the application of the load. Five additional groups of specimens were made similar to these in every respect except that the welds were eccentrically located with respect to the axis of the plate.

Figures 1 to 10 show the dimensions and details of the specimens.

Types *A*, *B*, *C* and *D* are single-strap lap joints in transverse shear. Types *E* and *F* are double-strap lap joints in transverse shear. Types *G* and *H* are single-strap lap joints in longitudinal shear, and types *I* and *J* are double-strap lap joints in longitudinal shear.

Base Metal

Specimens were made of regular structural grade steel. All specimens were designed to force failure to take place in the weld.

Weld-Metal

Specimens were welded with a $^{5}/_{32}$ inch diameter heavily coated electrode. The properties as reported by the manufactures are as follows:

Tensile strength	75,000 lb./sq. in.
Ductility	25% in 2 inches
Impact	40 foot-pounds Izod
Density	7.82 grams/cc.

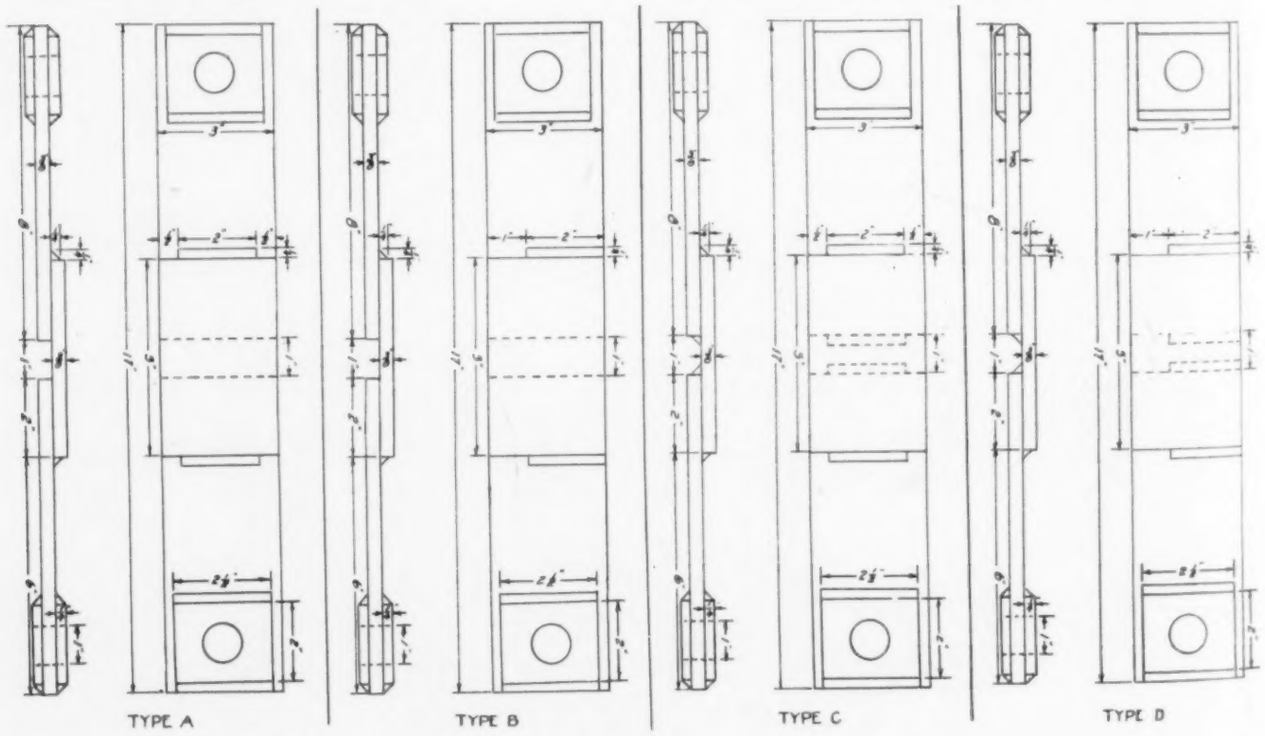
The welding was done with straight polarity (electrode negative). All welding was done by an experienced operator in the shops of the Soule Steel Company of San Francisco.

CALCULATION OF STRENGTH OF JOINTS

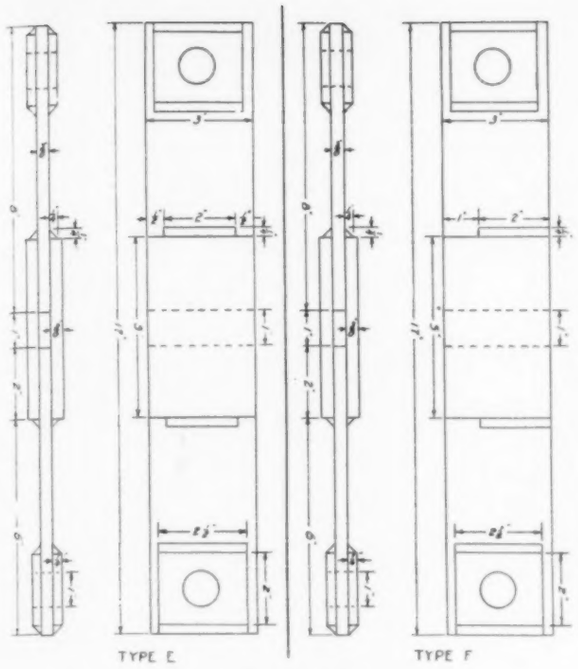
Photoelastic studies have shown that the distribution of stress in a weld is non-uniform. Numerous formulas

* Thesis prepared in the College of Engineering, Department of Civil Engineering, University of California. Contribution to the Fundamental Research Division, Welding Research Committee.

† Berkeley, California, May 1938.



Figs. 1 to 4



Figs. 5 and 6

have been proposed based on various assumptions. A common assumption is that the stress is uniformly distributed on the throat section. The formulas based on this assumption have been widely used and seem to give quite satisfactory results.

Transverse Fillet Weld

The stress is assumed to be a uniform tensile stress with the throat as the critical section. The following method of analysis has been presented by C. H. Jennings in the article, "Welding design" in the October 1936 number of the Transactions of the A. S. M. E., and by G. D. Fish in his book, Arc-Welded Steel Frame Structures (see Fig. 11).

A = Area of throat
L = Length of weld
S = Unit tensile stress in lb./sq. in.
P = Load in pounds
$P = SA$
$P = ShL \cos 45$
$P = 0.707\, ShL$

The load acting on the weld is eccentrically applied and a bending moment is set up which causes the plates to separate and results in a prying or tearing action on the weld. The magnitude of the effect of this action depends largely upon the stiffness of the two plates and is difficult to express mathematically. It is usually neglected in design. In the double-lap joint this effect is eliminated. In a joint of type C the prying action is eliminated, but the joint is still non-symmetrical. It should occupy a position somewhat intermediate between types A and B.

Longitudinal Fillet Welds

The stress in this case is assumed to be a uniformly distributed shearing stress. The same formula applies using the unit shearing strength in place of the unit tensile strength. Again non-symmetrical specimens are weaker, but the effect is usually neglected.

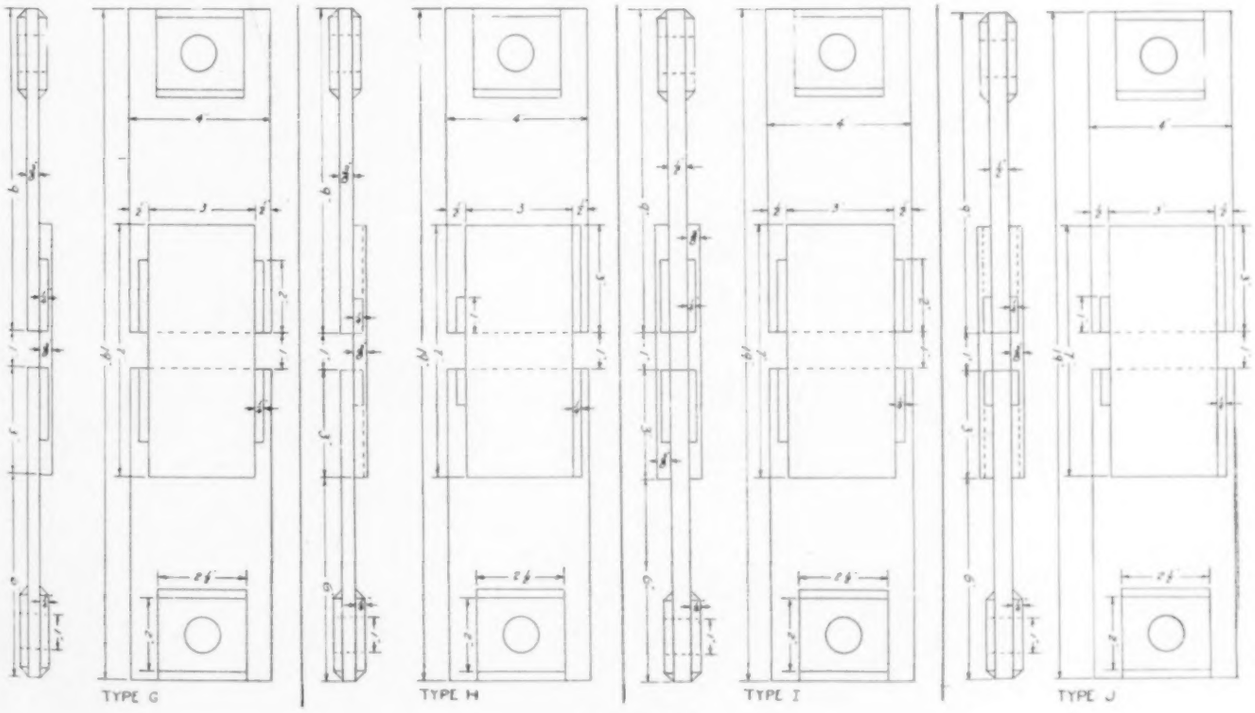
Eccentrically Loaded Specimens

Transverse Eccentric Load.—Assuming that the stress due to the eccentricity varies as shown in Fig. 12 (*b*), the stress at the top equals:

$$S = P/tL[1 + 6e/L]$$

or

$$P = StL/1 + 6e/L$$



Figs. 7 to 10

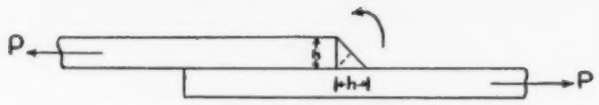


Fig. 11

Eccentric Side Welds.—A logical assumption to make in a case of this type is that the load is equally divided between the welds. Strain measurements taken on specimens of types *H* and *J* indicate that this is approximately true at the beginning of the loading.

Table 1 gives the theoretical strength of the joints tested, calculated on the assumptions outlined above and assuming the tensile strength of the weld-metal at 75,000 lb./sq. in. and shearing strength at 60,000 lb./sq. in.

Table 1—Theoretical Strength of Joints

Type	Ultimate Strength in Kips
A	26.6
B	10.6
C	53.2
D	21.2
E	53.2
F	21.2
G	42.4
H	21.2
I	84.8
J	42.4

TESTING PROCEDURE

All tests were performed in the Engineering Materials Laboratory of the University of California. The testing machine used was a three screw Riehle testing machine with a capacity of 300,000 lb. All specimens were painted with an inelastic paint to facilitate the observation of Luder lines.

Speed of Testing

The rate of speed used up to the yield point was 0.05 inch per minute. In some instances where a definite yield occurred, the speed was increased thereafter.

End Connections

In order to insure axial application of the load, it was decided to load the specimens by means of pin connections. The blocks resting on the heads of the testing machine had spherical bearings which afforded freedom of movement in a direction normal to that afforded by the pins.

Strain Measurements

Strain measurements were taken on one specimen of each type with a Federal $2^1/_2$-inch strain gage.

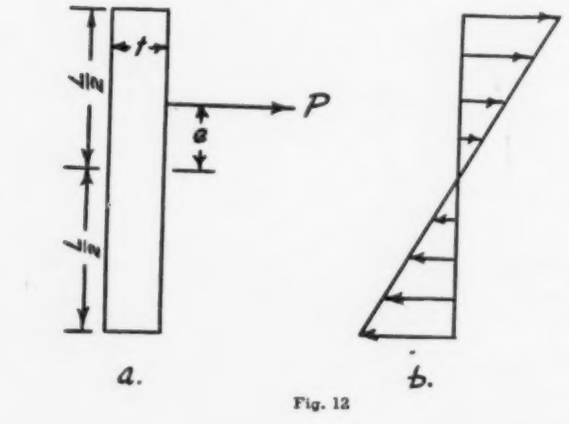
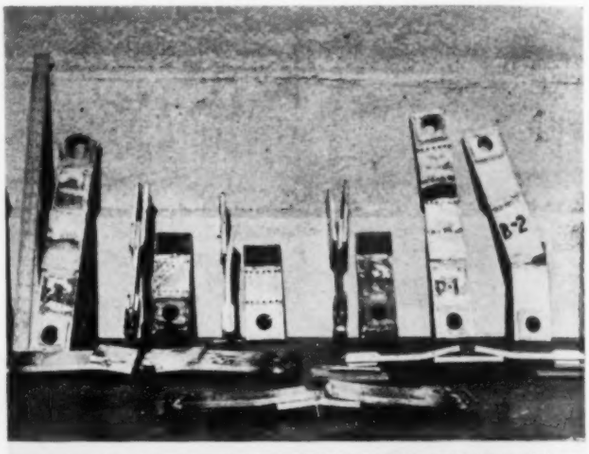


Fig. 12

Fig. 13—Typical Failures in End-Welded Specimens



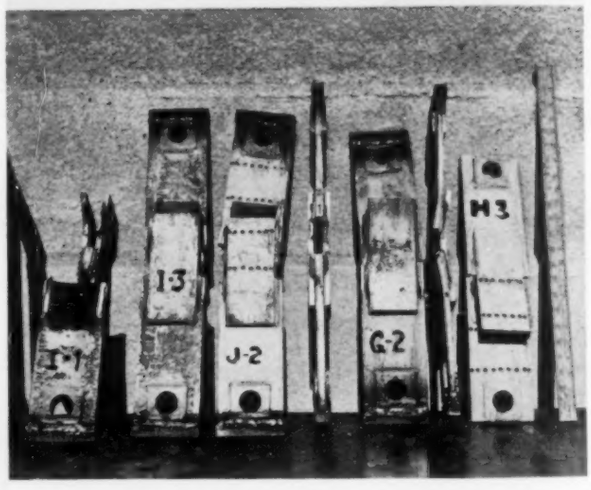


Fig. 14—Typical Failures in Side-Welded Specimens

TEST RESULTS

Comments on the Behavior of the Specimens

Figure 13 shows typical methods of failure in end-welded specimens, and Fig. 14 shows typical failures in side-welded specimens.

Type *A*. Failure in this type took place along the contact plane on the end of the cover plate. Figure 13 clearly indicates the extent of the prying action caused by separation of the plates. Practically all of the bending was confined to the main bars just above the welds.

Type *B*. The fracture in these joints started at the end of the weld nearest the axis of the specimen and progressed across with a tearing action. Bending similar to that in type *A* was not quite so pronounced, and in addition there was lateral displacement which is well illustrated in Fig. 13.

Types *C* and *D*. The prying effect was eliminated in these specimens by the welds at the end of the main plate. The bending of the main plate was reduced, and a sharp bend occurred in the coverplate between the welds. Specimen C-1 failed by tearing out a pinhole. The remaining specimens were reinforced by welding a $^3/_4$-inch bar across the ends and no further trouble of this kind was encountered.

Types *E* and *F*. No bending of the bars occurred in these forms. Lateral movement in the eccentric specimens was much less pronounced probably due to the restraining effect of friction between the bars.

Types *G* and *H*. Both main bars and coverplates bent into a shape very similar to type *C*. In type *H* the one-inch weld broke first and the load fell off to about one-half the ultimate, picked up about 3000 lb., and gradually fell off again as the three-inch weld was twisted off. Specimen G-1, shown in Fig. 13, failed in the coverplate.

Types *I* and *J*. The non-symmetrical welds in type *J* acted very similar to those in type *H*. No bending of the bars occurred in either type. Note the stretching of the edge of the plate in specimen I-1, Fig. 14. The deformation was about $^1/_8$ inch in this case.

General Remarks.—In all non-symmetrical joints bending started immediately upon application of the load and continued until the axis of loading passed through the welds. Lateral movement in those specimens having non-symmetrical welds did not start until much later when the welds were beginning to yield. Definite yield points by the drop of beam method were not obtainable on most specimens due to unequal bending or slipping between the plates.

Summary of Test Data

The results of the tests are tabulated in Table 2. Specimens C-1 and G-1 both failed in the bar and are not included in the averages although the load on specimen G-1 was above average at the time of failure.

Table 2—Summary of Test Results

Specimen	Ultimate Strength Kips	Average Ultimate Strength Kips	Unit Strength K/Lin. In.	Unit Strength K/Sq. In.
A-1	27.0			
A-2	23.6	25.2	12.6	71.2
A-3	25.0			
B-1	20.3			
B-2	20.0	20.0	10.0	
B-3	18.6			
C-1	50.1			
C-2	48.8	50.6	12.6	71.4
C-3	52.4			
D-1	42.6			
D-2	42.3	42.2	10.6	
D-3	41.7			
E-1	49.5			
E-2	55.0	51.9	13.0	71.9
E-3	51.1			
F-1	37.8			
F-2	36.8	37.5	9.4	
F-3	37.4			
G-1	39.8			
G-2	37.4	38.8	9.7	54.8
G-3	39.3			
H-1	28.6			
H-2	31.7	30.2	7.6	
H-3	30.2			
I-1	83.3			
I-2	81.9	80.8	10.1	57.1
I-3	77.3			
J-1	66.8			
J-2	66.8	64.2	8.0	
J-3	59.1			

DISCUSSION AND CONCLUSION

Specimens with Symmetrical Welds

Comparison of the actual strengths with the design values of Table 1 show that the assumptions and the method of calculation are satisfactory for all of these specimen groups. The value for the tensile strength was that reported by the manufacturer and probably was obtained in a straight tensile test of an all-weld-metal specimen. The stress in a fillet weld is assumed as a tensile stress, but actually the stress conditions are rather complicated, and its ultimate strength is only an approximation of the true tensile strength.

Effect of Non-Symmetrical Joints.—There is practically no difference between types *A* and *C*. Type *E* shows a very slight increase in strength. Type *J* is about 5% stronger than type *G*, the corresponding single lap joint. For joints of a similar type tested by the Structural Steel Committee of the American Bureau of Welding, the joint of type *E* was 35% stronger than type *A* and 15% stronger than type *C*. In the side-welded specimen the increase in strength reported was 4%. The above figures were for specimens having $^1/_4$-inch welds.

Specimens with Non-Symmetrical Welds

It is obvious that the assumptions used as a basis for design of these specimens were not satisfactory. However, the author has been unable to find any other basis for stress calculations for these specimens.

End-Welded Specimens.—The ultimate strength of these specimens is just about double the strength computed by the theory as outlined above. A likely explanation of the failure of this theory to approximate the actual stress conditions may lie in the lateral displacement. As the end of the weld nearest the axis is stressed more than the other end, it yields earlier and causes the specimen to deflect in a direction which will reduce the eccentricity of the load on the weld.

Side-Welded Specimens.—Again in this type the assumption of equal distribution between the welds gives too low a value. On the other hand, assuming that the load is distributed between the welds according to their length gives too high a theoretical strength. The true distribution evidently lies somewhere in between. In both types *H* and *J* the ultimate load is almost exactly three times the ultimate strength of the shorter welds.

CONCLUSIONS

The number of specimens tested was entirely too small. To reach any definite conclusions in a problem having as many variables as this, tests must be conducted with a large number of specimens. However, certain inferences may be drawn based on the limited number of tests performed.

The assumption of uniform distribution of stress on the weld throat gives a satisfactory result in ordinary weld design, but the assumption does not hold for cases of eccentric loading.

The effect of eccentricity of loading is not as serious as a strict application of the formula for combination of bending and direct stresses would indicate. There are factors which the theory does not recognize which tend to minimize the effect of eccentric loading. Using the usual working stress, the minimum factor of safety in the joints studied was 3.

WELDING MOLYBDENUM STEELS*

A Review of the Literature to July 1, 1937

By W. SPRARAGEN† and G. E. CLAUSSEN‡

* *This report is prepared under the auspices of*

THE LITERATURE DIVISION OF THE ENGINEERING FOUNDATION—
WELDING RESEARCH COMMITTEE

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NOTE: *Reviews on Welding Molybdenum-Vanadium Steel and Chromium-Molybdenum Steel appeared in* THE WELDING JOURNAL, **17** *(6) Research Suppl., 29, June 1938, and (7) Research Supplement, 11–34, July 1938, respectively.*

Summary

Most of the steels containing molybdenum are alloy steels, such as the S. A. E. 4000 Series, in which 0.2 Mo is added. The literature on the welding of these steels is summarized in separate sections of this and other reviews of literature on Welding Alloy Steels. The molybdenum steels strictly so-called, generally contain up to 1% Mo, the molybdenum being particularly effective in raising the strength of low-carbon steel at elevated temperature. The first sections of the present review deal with the welding of these carbon-molybdenum steels.

MOLYBDENUM IN STEEL

Molybdenum has a pronounced influence in refining the cast structure of steel. Substantially pure iron dissolves up to about 7% Mo, and the resulting solid solution appears to be retained at room temperature. Higher proportions of Mo form the hard compound Fe_3Mo_2.

† Secretary, Welding Research Committee.
‡ Research Assistant, Welding Research Committee.

The critical points of steel on heating are raised by molybdenum. The critical points of a molybdenum steel on cooling depend upon the maximum temperature from which the steel is cooled as well as on the rate of cooling. Molybdenum has a great effect in slowing down the rate of transformation of austenite, if the molybdenum is in solid solution.

Molybdenum steels have higher strength than plain carbon steels of the same carbon content at elevated temperature. The molybdenum steels also seem to preserve a higher degree of stiffness at higher temperatures than plain carbon steels.

WELDING CARBON-MOLYBDENUM STEELS

Mechanical Properties

Process approval tests for the Navy require preheating the welds to 300° F., stress relieving 4 hours at 1200° F. and slow cooling after welding (C 0.30 max., Mn 0.80 max., Mo 0.40 to 0.80). Welds have tensile strengths of 75,000 lb./in^2. Weld metal and welds in this type of steel at 450° C. have better creep resistance than the base metal.

Butt welds in a machined plate of acid open-hearth steel $\frac{1}{2}$ inch thick containing 0.16 C, 0.68 Mn, 0.06 Si, 0.15 Ni, 0.25 Mo after heating at 650° C. for 2 or 36 hr. and furnace cooled have practically the same tensile strength, elongation and impact value as the parent metal.

Short-time creep tests (50 hr., 500° C.) on oxyacetylene and shielded arc butt welds in steels 0.63 to 0.91 inch thick containing 0.11–0.14 C, 0.16–0.24 Si, 0.47–0.59 Mn, 0.18–0.19 Cu, 0.35–0.48 Mo. give better values for welds made with austenitic steel filler rods than for base metal.

Recovery

From the standpoint of recovery, molybdenum is the easiest element to control in covered electrodes. In one investigation the recovery of molybdenum from a waterglass coating containing ferromanganese, graphite and ferromolybdenum was 76 to 100%. The percentage recovered decreased as the molybdenum content of the coating increased.

Forge Welding

Molybdenum and phosphorus are the only two common elements that do not interfere with the forge welding of steel.

Thermit Welding

Satisfactory thermit welds can be made in C-Mo steel rails.

Atomic Hydrogen Welding

Iron alloys with up to 22% Mo may be welded successfully by means of the atomic hydrogen process without flux.

Resistance Welding

Flash welded 0.15 C, 0.78 Mn, 0.30 Mo, 0.23 Cu superheater tubes gave higher tensile strength and ductility than flash welded plain carbon steel.

Butt joints made by flash welding in carbon-molybdenum steel superheater tubing behaved satisfactorily in tension, bend and rolling-in tests.

Flame Cutting

Pure molybdenum does not cut so rapidly as iron. One investigator states that 5.5% Mo added to a steel containing 8 W, 1.4 Cr, 1 C rendered the steel uncutable by the oxyacetylene cutting torch.

WELDING MANGANESE-MOLYBDENUM STEELS

In welding, molybdenum has little effect on hardness. In steels (C 0.17, Mn 1.57, Mo 0.38) and (C 0.12, Mn 1.00, Mo 0.49) the welds had higher static strength than base metal, but lower ductility and impact tensile value. Stress relieving was advantageous. The Committee on Low-Alloy Steels classed steels with 0.15–0.22 C, 0.88–1.59 Mn, 0.09–0.44 Si, 0.22–0.34 Mo as moderately air hardening.

WELDING NICKEL-CHROMIUM-MOLYBDENUM STEELS

All-weld-metal containing 1 Ni, 0.75 Mo, 0.25 Cr deposited in a Cromansil plate 1 inch thick, according to one investigator, had a yield strength of 72,000 lb./in.^{2}, tensile strength = 88,000 lb./in.^{2}, 24% elongation in 2 inches, 38% elongation in free-bend test.

Welding Molybdenum Steels

INTRODUCTION

MOST of the steels containing molybdenum are alloy steels, such as the S. A. E. 4000 Series, in which 0.2 Mo is added. The literature on the welding of these steels is summarized in separate sections of this and other reviews of literature on Welding Alloy Steels. The molybdenum steels strictly so-called, generally contain up to 1% Mo, the molybdenum being particularly effective in raising the strength of low-carbon steel at elevated temperature. The first sections of the present review deal with the welding of these carbon-molybdenum steels.

MOLYBDENUM IN STEEL

The effects of molybdenum in steel are stated in great detail in the *Alloys of Iron and Molybdenum*, by J. L. Gregg (McGraw-Hill Book Co., 1932) and in *Metals Handbook* (1936 Edition, pp. 405–410). Molybdenum in the amounts usually added plays no important part in steel furnace reactions. Added as calcium molybdate in the furnace, the recovery of molybdenum in the steel is 90%. Yet pure molybdenum, like tungsten is readily oxidized although less readily than iron. In air at 650° C. volatile molybdenum oxide (MoO_3) is formed. During the forging of high-molybdenum steels (over 1% Mo) gray fumes of the oxide may be formed, unless the surface is protected by borax or other agents. Molybdenum sulfide (MoS_2) is formed only in high-molybdenum alloys. At 800° C. molybdenum reacts with carbon to form Mo_2C; the carbide in molybdenum steel may be Fe_3Mo_3C or similar compound. The density of molybdenum (10) is only half that of tungsten.

Molybdenum has a pronounced influence in refining the cast structure of steel. Substantially pure iron dissolves up to about 7% Mo, and the resulting solid solution appears to be retained at room temperature. Higher proportions of Mo form the hard compound Fe_3Mo_2. The critical points of steel on heating are raised by molybdenum. The critical points of a molybdenum steel on cooling depend upon the maximum temperature from which the steel is cooled as well as on the rate of cooling. Molybdenum has a great effect in slowing down the rate of transformation of austenite, if the molybdenum is in solid solution. It is believed that high temperatures (900° C.) are required for solution of molybdenum because the maximum lowering of the critical points is secured only by cooling from 900° C. or so. Besides the deep hardening and air hardening characteristics of molybdenum steels, to which is attributed the unusual, striated form of the pearlite in these steels, they have higher strength than plain carbon steels of the same carbon content at elevated temperature. The molybdenum steels also seem to preserve elasticity at higher temperatures than plain carbon steels. All these factors may have a bearing on the necessity for special treatment (preheating and stress relieving) of some carbon- and alloy-molybdenum steels during welding under unfavorable conditions. Molybdenum is perhaps the only element that to a large extent eliminates temper brittleness in otherwise temper brittle steels, such as steels containing 0.25 C, 3 1/2 Ni, 1 1/4 Cr. Like other alloying elements, molybdenum lowers the electric and thermal conductivity of steel, 5% Mo increasing the electric resistivity of iron 100%.

WELDING CARBON-MOLYBDENUM STEELS

Mechanical Properties

In describing the process approval tests for C-Mo steel of the Navy Bureau of Engineering, Stewart[1] states the mechanical properties that are required of 60° V butt welds in plate 3/4 inch thick, Table 1, with 1/4 inch spacing and a backing strip. The preheating temperature is at least 150° C. (300° F.), and the weld must be held 4 hr. at 590–650° C. (1100–1200° F.) and slowly cooled in the furnace to below 375° C. (700° F.) after welding. The test results quoted in Table 1 were obtained from welds in plates 12 x 12 x 1 inch (no details). The welds were stress relieved 4 hr. at 650° C. The molybdenum content of the weld-metal was below specifications and the

Table 1—Mechanical Properties Required of and Obtained from Arc-Welded C-Mo Steel. Stewart[1,2]

Requirements

	Composition						Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 In.	Reduction of Area, %	Cold Bend Test
	C	Mn	Si	P	S	Mo					
Forged base metal	0.30 max.	0.80 max.	0.15–0.30	0.040 max.	0.040 max.	0.40–0.60	45,000	70,000	30	35	180° on a diameter of 1 inch
All-weld-metal	...	...	...	0.040 max.	0.045 max.	0.40–0.60	40,000 min.	65,000 min.	20	..	....

All-weld-metal specimen was $^1/_2$ inch diameter, $2^1/_4$ inches parallel section.

Bend elongation on butt-welded specimen (weld removed flush, $^3/_4$ x $1^1/_8$ inches) must be at least 30%. The strength of a specimen of the joint ($1^1/_2$ inches wide, 6 inches parallel section) must be at least 65,000 lb./in.²

Test Results

	Composition						Proportional Limit, Lb./In.²	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 In.	Reduction of Area, %	Brinell Hardness
	C	Mn	Si	P	S	Mo						
Cast steel	0.31	0.56	0.25	...	...	0.49	54,000	59,250	86,600	21.8	36.7	152
All-weld-metal	0.08	0.60	0.14	0.004	0.025	0.32*	51,250	....	68,500	31.5	62.4	144
Butt weld	(consisting of the above plate and weld-metal)						....	....	75,600	15.3	12.1	...

* Less than 0.02 Cr.

Table 2—Materials Used by Detroit Edison Company and University of Michigan[46]

		Weld Made with Electrodes					
		A		B		C	
Element	Tube Metal	Weld	Electrode	Weld	Electrode	Weld	Electrode
Carbon	0.14	0.11	0.10 to 0.15	0.11	0.07	0.11	0.12
Molybdenum	0.50	0.00	...	0.38	0.42	0.49	0.48
Manganese	0.50	0.48	...	0.47	0.34	0.52	0.64
Silicon	0.18	0.15	...	0.24	0.15	0.08	0.08
Sulphur	0.022	0.022	...	0.013	..	0.014	0.035
Phosphorus	0.014	0.022	...	0.016	..	0.026	0.035

carbon content of the plate was just above specifications, but in other respects the welds were acceptable. Time-extension curves on specimens $^1/_2$ inch diameter, 2-inch gage length at 450° C. (850° F.) are shown in Fig. 1. The creep specimens were taken from the welded test plate described in Table 1. At 1000 hr. and 450° C., unwelded base metal had an extension of 0.0013 inch per inch at 25,000 lb./in.² and 0.0003 inch per inch at 20,000 lb./in.² Figure 1 shows that the butt weld and all-weld-metal were more resistant to creep than unwelded base metal at 450° C. The temporary increase in creep rate of the all-weld-metal specimen at 25,000 lb./in.² was not explained. Although Stewart recommends preheating to at least 150° C., N. L. Mochel (private communication, August 1938) has found it desirable in some circumstances to preheat to higher temperatures up to 510° C. (950° F.).

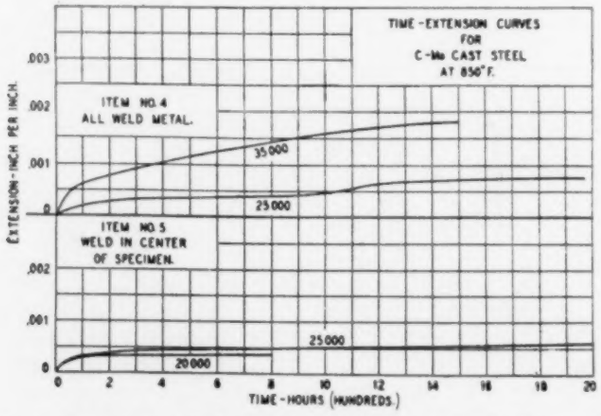

Fig. 1—Creep Tests of C-Mo Weld-Metal and Weld at Tensile Stresses of 20,000, 25,000 and 35,000 Lb./In.² Stewart[2]

An investigation consisting of static and impact tensile and charpy notch-impact tests at room temperature, and of extended time tensile tests at 500° C. (925° F.) has been carried out by the Detroit Edison Company and University of Michigan[46] on experimental butt welds in seamless tubing $6^5/_8$ inches O.D., $^{13}/_{16}$-inch wall thickness, Table 2. The tubing was heated 1 hr. at 840° C. (1550° F.) and cooled in furnace before welding. Circumferential U-shaped joints were made without preheating and were stress relieved 1 hr. at 600° C. (1100° F.). Static tension specimens were 0.500 inch diameter, $2^1/_4$ inches parallel section. Impact tension specimens were 0.250 inch diameter, $1^1/_4$ inches parallel section. In both specimens the butt weld was in the center of the parallel section. The static tension stress-strain curves were obtained with a mirror extensometer sensitive to 2.8 millionths of an inch per inch. The extended time tests consisted in applying a constant load and recording the time elapsed before fracture. The results are summarized in Table 3.

The static strength of the welds was higher than that of unwelded base metal at room temperature, but the elongation was lower. The differences among the welds were insignificant. Despite defects in some of the welds fracture always occurred outside. There was little difference among the welds at 500° C. in the short time tensile tests, except that weld *A* fractured in the weld. Faulty welding accounted for one of the welds made with electrode *C* fracturing in the junction between weld and base metal. Although the Charpy tests failed to differentiate among the welds and indicated that the welds had greater notch-impact value than base metal, the impact tensile tests showed that, with the scarf included in the specimen, the welds had lower impact tensile value than base metal, and that weld *A* was superior to *B* and *C*. The latter failed at the scarf, whereas

Table 3—Static Tensile and Impact Tests[46] of Arc-Welded Carbon-Molybdenum Steel Pipe. Pipe Annealed at 840° C. Welds Stress Relieved at 600° C. Averages of Two Specimens

Specimen	Proportional Limit, Lb./In.²	Yield Strength, Lb./In.² 0.1% Offset	0.2% Offset	Tensile Strength, Lb./In.²	Elongation, % in 2 Inches	Reduction of Area, %	Location of Fracture
Static Tensile Tests at Room Temperature							
Unwelded base metal	17,500	29,500	30,800	55,400	39.0	67.8	Center
Weld *A*	30,000	38,800	38,800	60,800	24.0	63.7	Outside weld
Weld *B*	31,300	40,000	41,000	60,100	19.5	63.5	Outside weld
Weld *C*†	26,300	36,300	37,800	60,100	20.5	63.4	Outside weld
Static Tensile Tests at 500° C. (925° F.) (A. S. T. M. Std. E 21-34 T)							
Weld *A*	10,000	26,000	27,800	41,800	24.0	69.2	In weld
Weld *B*	15,000	28,900	32,400	49,800	19.0	68.1	Outside weld
Weld *C**	16,500	29,000	32,000	50,500	19.0	66.5	Outside weld
Weld *C*†	15,000	29,500	32,000	48,500	6.0	4.3	Weld junction

* Satisfactory weld.
† Defects visible in weld.

Impact Tests at Room Temperature

Material	Tensile Impact Tests Spec. No.	Impact Strength, Ft.-Lb.	Elongation in 1¼ In. Per Cent	Reduction of Area, Per Cent	Remarks	Charpy Impact Tests Spec. No.	Impact Strength, Ft.-Lb.
Unwelded base metal	1	115	34.4	63.3		1	38
	2	148½	43.8	66.5		2	34½
	Avg.	132	39.1	64.9		Avg.	36
Weld *A*	2	97	24.0	60.3		1	50½
	3	117½	28.7	69.6		18	42½
	Avg.	107	26.3	65.0		Avg.	46½
Weld *B*	4	39	9.4	50.4	Broke at flaw	5	46
	7	45	11.3	56.9		6	38½
	Avg.	42	10.3	53.7		Avg.	42
Weld *C*	1	65	16.3	30.4	Large flaw‡	15	49½
	14	107½	24.4	37.4		16	38½
	Avg.	86	20.3	33.9		17	39
						Avg.	42

‡ Did not break at large external flaw. A smaller internal flaw was visible in the fracture.

weld *A* failed in the center of the weld in the impact tensile tests.

Table 4 summarizes the results of the extended-time fracture tests at 500° C. under constant stress. The results were picked from a logarithmic plot of elapsed time to fracture versus stress, which has been found to be a straight line. Since the material possessing the greater stress for a given fracture time will also exhibit the greater creep resistance and load-carrying ability, weld *A* is inferior to *B* and *C*. At an elapsed time of 7.12 hr., weld *A* fractured with only 18% elongation in 2 inches. Welds *B* and *C* did not exhibit decreased ductility as the time for fracture was increased except when fracture occurred in the weld junction (weld *C*).

Table 4—Extended-Time Fracture Tests[46] of Butt-Welded Carbon-Molybdenum Steel Pipe Using Three Different Electrodes (see Table 2)

Specimen	Short Time Tensile Strength, Lb./In.²	Tensile Stress, Lb./In.², for Designated Fracture Time, Hr. 0.10	1.0	10.0	20.0
Weld *A*	41,800	39,500	36,500	34,000	33,200
Weld *B*	49,800	49,800	49,500	49,200	48,900
Weld *C*	49,500	49,400	49,300	48,500	47,900

Summarizing the results of the Detroit Edison Company — University of Michigan investigation, it is seen that the welds made with three different types of electrodes were equivalent in static short time tensile strength and Charpy value at room temperature. Weld *A* possessed better impact tensile value, but lower extended-time fracture strength than welds *B* and *C*.

The effect of preheating to 210 to 320° C. (400 to 600° F.) on welding carbon-molybdenum steel (0.15 C, 0.50 Mo, 0.53 Mn) with a carbon-molybdenum electrode according to Rohrig,[47] is in general slightly to decrease the hardness of the joint, Table 5. Unaffected base metal was 64 to 74 B Rockwell.

In no specimen was the hardness above 238 Brinell, which was observed in the weld-metal of the unpreheated single-bead specimen. The microstructures of weld metal, heat-affected zone and base metal were almost identical at corresponding points in the single-bead specimens, the principal difference being that the sorbitic structure of the weld-metal in the preheated section contained more ferrite than the weld metal of the specimen that was not preheated. The weld metal was the hard zone in the butt welds. The change in hardness from

Table 5—Hardness of Arc-Welded Carbon-Molybdenum Steel Pipe. Rohrig[47]

Preheated	Stress Relieved 90 Min. at 600° C. Single Bead Welds*	Maximum Rockwell B Hardness
No	No	99.5
No	Yes	97
Yes	No	93.5
Yes	Yes	93
Multi-Layer Butt Welds in Pipe ¾ Inch Wall Thickness		
No	Yes	87.5
Yes	Yes	77
Multi-Layer Butt Welds in Pipe 1⅛ Inch Wall Thickness		
No		90
Yes		90

* Single bead deposited on surface (size of electrode and thickness of pipe not stated).

Table 6—Mechanical Properties of Arc-Welded 1/4% Mo Steel. Hopkins[3]

Time of Treatment at 650° C.	Yield Strength, Lb./In.²		Tensile Strength, Lb./In.²		Elongation, % in 2 Inches		Reduction of Area, %		Maximum Brinell Hardness		
	Base Metal	All-Weld-Metal	Base Metal	All-Weld-Metal	Base Metal	All-Weld-Metal	Base Metal	All-Weld-Metal	Weld	Heat-Affected Zone	Base Metal
2 hr.	35,250	40,600	60,200	58,500	35.5	35.0	60	59	109	118	109
36 hr.	33,000	41,500	58,250	58,150	38.0	37.5	66	70	109	121	106

Charpy Impact Value, Ft.-Lb.

Time of Treatment at 650° C.	+21° C.			−32° C.			−46° C.		
	Weld	Heat-Affected Zone	Base Metal	Weld	Heat-Affected Zone	Base Metal	Weld	Heat-Affected Zone	Base Metal
2 hr.	37.5	47.5	35.0	36.9	45.7	4.7	30.8	28.0	2.5
36 hr.	37.4	53.3	33.0	34.8	38.3	2.6	30.5	30.7	2.0

base metal to weld-metal was abrupt in the fusion zone. The weld metal of the preheated specimens was pearlitic, whereas the weld-metal of the specimens not preheated was sorbitic. In the specimens $1^1/_8$ inches thick the maximum hardness of the weld that was not preheated was found in the first bead. In the preheated weld the maximum hardness was in the top bead. Widmannstätten structure was absent in all specimens.

Butt welds in a machined plate of acid open-hearth steel $^1/_2$ inch thick containing 0.16 C, 0.68 Mn, 0.06 Si, 0.15 Ni, 0.25 Mo were tested by Hopkins,[3] Table 6. The tensile specimens were 0.505 inch diameter. All specimens were heated 2 or 36 hr. at 650° C. and furnace cooled. The welds were made with covered electrodes, $^5/_{16}$ inch diameter, 450 amps., of the same composition as base metal. The weld-metal contained 0.08 C, 0.60 Mn, 0.025 Si, 0.05 Ni, 0.25 Mo. Microscopic examination revealed that the plate was coarse grained whereas the heat-affected zone and weld-metal were fine grained. Hopkins concluded that the inadequate low-temperature notch-impact value of the plate was related to its coarse structure, which was thought to reflect the method of manufacture. The C-Mo weld-metal had good tensile and Charpy impact value in the heat-treated condition. No results were given for as-welded specimens.

The effect of welding speed on the maximum hardness of the heat-affected zone beneath a single bead (9 inches long) of a bare electrode $^5/_{32}$ inch diameter deposited automatically (A.C., 23 volts, 375 amps.) on the unmachined surface of 9 x 2 x $^1/_2$ inch pieces of C-Mo steel was determined by Theisinger,[4] Table 7. The increases in hardness are rather small; consequently Theisinger concluded that molybdenum "places no difficulties in the way of welding."

Table 7—Maximum Vickers Hardness in the Heat-Affected Zone of Surface Welded C-Mo Steels. Theisinger[4]

C	Mn	Si	Mo	Unaffected Base Metal	Welding Speed 6 Inches per Min.	Welding Speed 12 Inches per Min.
0.25	0.85	0.18	0.24	180	210	255
0.15	0.78	0.17	0.48	180	205	240

Short time creep tests (50 hr., 500° C.) were made by Schottky and Ruttmann[5] on butt welds in steels 0.63 to 0.91 inch thick containing 0.11–0.14 C, 0.16–0.24 Si, 0.47–0.59 Mn, 0.18–0.19 Cu, 0.35–0.48 Mo. The welds were made by the oxyacetylene process or with covered electrodes. The filler rods contained 18 Cr, 8 Ni or 25 Cr, 20 Ni, or were alloyed with fractional percentages of Mn or Mo, and the strains were measured on a gage length of 4 inches over the weld and heat-affected zone. In nearly all instances the austenitic welds, which were not heat-treated, had higher short time creep strength than unwelded base metal. The unheat-treated low-alloy steel welds also had higher short time creep strength than unwelded base metal. Heating $^1/_2$ hr. at 920 to 930° C. had no effect, but heating 500 hr. at 500° C. lowered the short time creep strength below base metal. Inadequate penetration also resulted in low short time creep strength for welds.

Breathing tests were carried out by Moore[6] on a welded drum with tube holes drilled through, or at the edge of, the welds, Table 8. The drum was 42 inches inside diameter, $1^3/_{32}$ inches wall thickness, the plate being A. S. T. M.—A 150–35 T, Grade B. The holes were $2^{17}/_{32}$ to $4^1/_{32}$ inches diameter, 36 holes being through or at the edge of welds. The remaining 171 holes were drilled through plate. Tubes were expanded into the holes by rolling. The welds were of U type and were made with covered electrodes. A reduced section specimen (Fig. P 2, A. S. M. E. Power Boiler Code) had a strength of 78,500 lb./in.² A bend specimen $^3/_4$ inch thick, 3 inches radius of bend, cracked at 110° with 20% elongation in the outer fibers. A hydrostatic pressure of 580 lb./in.² (21,000 lb./in.² tensile stress in fibers) was applied to the drum 15 times a minute for 40 days. There were no cracks after the test.

The maximum hardness of the heat-affected zone of a weld in cast C-Mo steel containing 0.3 C, 0.5 Mo was reported by Maack[7] to be 208 Brinell. The weld was not heat treated. Base metal was 170 to 175 Brinell, weld-metal was 204 Brinell, maximum. The electrodes were of such composition that they deposited steel containing approximately 0.12 C, 0.08 Si, 0.64 Mn, 0.48 Mo, less than 0.035 P and S.

According to E. C. Chapman,[8] 0.5% Mo increases the

Table 8—Welds Tested by Moore[6]

	C	Mn	Si	Mo	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 Inches	Reduction of Area, %
Base metal	0.26	0.84	0.19	..	43,100	72,800	26.5	.....
All-weld-metal	0.09	0.33	0.04	0.20*	56,000 to 63,500	73,000 to 78,000	17 to 21	26.8 to 31.2

* 0.031% nitrogen.

tensile strength of stress-relieved, plain carbon weld-metal by 8000 lb./in.² (no details). Without supplying details, Tofaute and Ruttmann[9] stated that the creep strength of welded C-Mo, Cu-Mo and Cr-Mo boiler plate at 500° C. using several welding processes did not differ as much as ±10% from unwelded base metal.

Recovery

The only published record of recovery of molybdenum from a bare welding rod is supplied by Keel,[10] Table 9, who used oxyacetylene welding. In comparison with the other elements in the rod, the recovery of molybdenum was highest, with the exception of carbon, whose recovery is known to depend on mixture ratio. According to Air Reduction Sales Co. (private communication, October 1938), there have been instances of complete recovery of molybdenum in oxyacetylene welding with a bare rod containing 0.50 Mo.

Table 9—Recovery of Molybdenum in Oxyacetylene Welding. Keel[10]

	C	Si	Mn	Cu	Mo
Rod	0.06	0.12	0.85	0.35	0.11
Weld metal	0.06	0.02	0.53	0.20	0.09

From the standpoint of recovery, molybdenum is the easiest element to control in covered electrodes, according to Chapman[8] and Harris.[11] Holmberg[12] stated that up to 1% Mo has been introduced into weld-metal from coatings. Using methods described in earlier reviews (see review of literature on Welding Nickel Steels THE WELDING JOURNAL, **17** (5) 1–17, May 1938, Table 24), Losana and Jarach,[13] Table 10, found that recovery of molybdenum from a waterglass coating containing ferromanganese, graphite and ferromolybdenum was 76 to 100%. The percentage recovered decreased as the molybdenum content of the coating increased. Molybdenum slightly increased the recovery of carbon. Manganese had no effect, Losana and Jarach concluded.

Table 10—Recovery of Molybdenum from Coated Mild Steel Electrodes. Losana and Jarach[13]

No.	(Mn)	(Si)	(C)	(Mo)	(Mo)¹	[Mn]	[C]	[Mo]	[Mo]/(Mo)¹
1	0.84	2.10	2.40	6.25	2.5	0.03	0.07	1.98	0.79
2	0.80	2.03	2.51	10.62	4.2	0.04	0.12	3.43	0.82
3	0.76	2.08	2.39	16.80	6.7	0.06	0.21	5.11	0.76
4	7.62	2.21	2.46	5.40	2.1	0.42	0.15	2.35	1+
5	7.20	2.12	2.34	9.82	3.9	0.49	0.19	3.52	0.90
6	6.90	2.03	2.26	15.96	6.4	0.58	0.25	5.25	0.82
7	15.2	2.18	2.31	4.98	2.0	1.16	0.38	2.12	1+
8	14.6	2.07	2.54	8.98	3.6	1.32	0.49	3.19	0.89
9	13.9	1.98	2.60	14.80	5.9	1.60	0.61	4.47	0.76

( ) Weight % constituent in coating.
[ ] Weight % constituent in deposit.
(Mo)¹ Percentage of Mo in electrode calculated on basis of core rod of electrode.
[Mo]/(Mo)¹ Approximate recovery of Mo.
The ferromolybdenum contained 49.70 Mo, 0.36 Mn, 0.62 Si, 0.64 C, 0.036 P, 0.024 S.

Pick Up

A spark spectrographic method was used by Coombs[14] to determine the pick up of molybdenum by weld-metal deposited from covered unalloyed electrodes (0.13 to 0.18 C, reversed polarity) in a 60° V butt weld in plates ½ inch thick containing 0.15 C, 0.78 Mn, 0.17 Si, 0.48 Mo. Two welds were studied, Figs. 2 and 3. A series of intersecting grooves (10 to the inch) was milled on the cross section of the weld and base metal. The spark was excited at the tops of these intersecting grooves. The internal standard method with densitometer was used, the spark lines being in the region 2800 to 3200 Å. A set of 12 molybdenum steels containing 0.03 to 0.65 Mo, with, unfortunately, 0.2 V was used for comparison. The accuracy was estimated to be 5% down to 0.15% Mo; greater accuracy was claimed at lower percentages.

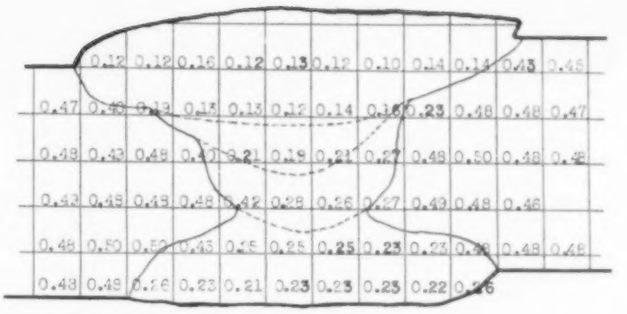

Fig. 2—Spectrographic Determination of Molybdenum Pick Up in Arc Welds. Coombs.[14] Base Metal ½ Inch Thick, 0.15 C, 0.78 Mn, 0.17 Si, 0.48 Mo. 60° V, 3 Layers, 1 Seal Bead, No Separation, 190 Amps., 30 Volts, Reversed Polarity

The results showed that the molybdenum content of the weld metal was different in each layer depending upon the ratio of metal from electrode to metal melted from the plates and preceding beads. The approximate molybdenum contents were:

First layer = 0.28 Mo
Second layer = 0.17 Mo
Third layer = 0.14 Mo
Fourth layer = 0.10 Mo
Seal head = 0.23 Mo

In each layer the molybdenum is uniformly distributed except close to the fusion line. There was no diffusion or displacement of molybdenum in the plates beyond the fusion line. Brand[15] was successful in detecting Mo in a steel weld by means of a spectrograph using lines 3798.3, 3864.1 and 3902.9 Å.

In contrast with Coombs' results, Blasko, Smart and Decker[46] found that there was no molybdenum in the weld-metal in multi-layer butt welds in carbon-molybdenum piping made by unalloyed covered electrodes.

Forge Welding

Molybdenum and phosphorus, according to Speller,[16] are the only two common elements that do not interfere with the forge welding of steel. Burgess and Aston[17] (1909) had no difficulty forge welding iron containing 10 Mo, 2 Si. Martin[18] stated that water gas-welded boiler drums are usually made of steel containing 0.1 to 0.5

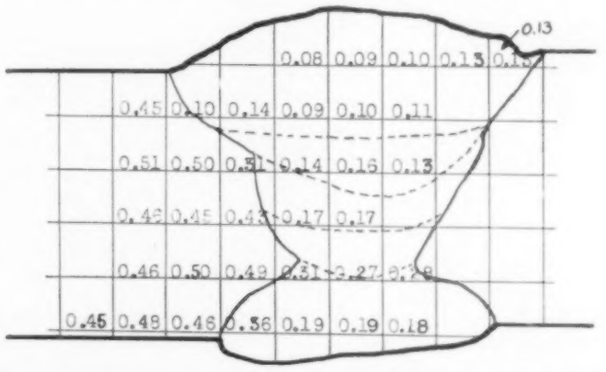

Fig. 3—Spectrographic Determination of Molybdenum Pick Up in Arc Welds. Coombs.[14] Same Base Metal as Fig. 2, but 4 Layers, 1 Seal Bead, No Separation, 130 Amps., 28 Volts, Reversed Polarity, 60° V.

Table 11—Mechanical Properties of Water Gas-Welded C-Mo Steel. Prömper and Pohl[20]

Temperature, Degrees Cent.	Yield Strength, Lb./In.²		Tensile Strength, Lb./In.²		Elongation, % in 8 Inches		Notch Impact Value, Mkg./Cm.²	
	Unwelded*	Welded	Unwelded*	Welded	Unwelded*	Welded	Unwelded	Welded
20	41,500	43,000	61,500	54,500	25.5	7.9	21.9	14.6
500	31,400	29,000	46,500	39,800	25.5	6.0	18.1	12.1

* Unwelded plate for tests was only 0.91 inch thick. Results are averages of three tests each.

Mo, which agrees with Pohl's[19] statement that molybdenum is beneficial in the water gas welding of steel.

Automatic water gas welds were made by Prömper and Pohl[20] in steel 1.26 inches thick containing 0.15 C, 0.00 Si, 0.50 Mn, 0.020 P, 0.017 S, 0.34 Mo. The axis of the unwelded tensile specimens was in the direction of rolling. The welded tensile specimens were straightened at a red heat and normalized (no details). The notch impact specimens were 1.18 x plate thickness x 6.3 inches long. The diameter of the notch was 0.16 inch. The notch was placed in the weld. The welded plates for the notch-impact specimens were not straightened, but were normalized. The high temperature tensile tests were made in a mixture of 1 part calcium nitrate and 1 part sodium nitrate at a speed of 70 lb./in.² per second.

The results in Table 11 show that the normalized water gas welds had considerably lower mechanical properties than the unwelded steel. Some of the welded tensile specimens broke in the weld (no details). The microstructure of the as-welded specimens revealed a good junction and uniform pearlite distribution, but the welded area of the normalized welds appeared decarburized.

Thermit Welding

According to Deppeler,[21] satisfactory thermit welds can be made in C-Mo steel rails (no details).

Atomic Hydrogen Welding

Warner[22] successfully welded iron alloys with up to 22% Mo by means of the atomic hydrogen process without flux.

Resistance Welding

The best machine settings for flash welding superheater tubes 1.18 inches O.D., 0.12-inch wall containing 0.15 C, 0.78 Mn, 0.16 Si, 0.30 Mo, 0.23 Cu, 0.027 P, 0.024 S, were found by Czternasty[23] to be somewhat different from those for plain carbon steel. Using the best machine setting, Czternasty found that tensile strength and ductility were higher than for the flash-welded plain carbon steel, Table 12. The bend tests were made with grooved rollers (3.5 inches diameter at base of groove) and grooved plunger (twice the tube diameter). The specimen was 12 inches long, filled with lead to prevent buckling and placed on the rollers, the open distance between which was 5 times the tube diameter. The tensile specimens were 12 inches long, had plugged ends, were not machined and fractured outside the weld in most instances. The results in Table 12 are averages of 3 to 5 specimens, all of which had practically the same properties.

Table 12—Mechanical Properties of Flash-Welded Superheater Tubes. Czternasty[23]

Steel	Yield Strength, Lb./In.²		Tensile Strength, Lb./In.²		Bend Angle, Degrees	
	As-Welded	Normalized	As-Welded	Normalized*	As-Welded	Normalized*
Plain Carbon†	....	44,000	....	65,000	...	157
C-Mo Steel	47,000	40,300	71,500	71,000	180	180

* Normalized at 900° C.
† 0.19 C, 0.62 Mn, 0.21 Si, 0.025 P, 0.02 S.

Whereas the microstructure of the welds made with the best machine setting was uniform, all impurities being eliminated by the high upset pressure, the welds made with the upset pressure (2100 lb./in.²) suitable for plain carbon tubing had a broad decarburized zone with inclusions at the weld, which caused low-bend ductility, such as 40°. To be sure, there was a slightly decarburized zone in the best welds. The typical Widmannstätten structure of overheated C-Mo steel was present in the unheat-treated welds but not in the normalized welds.

Creep tests made in accordance with German standards (VDE) on flash welds made with the procedure suitable for plain carbon steels revealed a creep strength (10 x 10^{-4}% elongation per hr. between the 25th and 35th hour) of 17,100 lb./in.² for unwelded base metal, and 15,700 lb./in.² for welds, whether or not normalized. The steel in the creep tests contained 0.17 C, 0.80 Mn, 0.19 Si, 0.30 Mo, 0.25 Cu. It should be mentioned that Czternasty referred to his steel as a molybdenum-copper steel.

Butt joints made by flash welding in carbon-molybdenum steel superheater tubing behaved satisfactorily in tension, bend and rolling-in tests, according to Schottky.[24]

Flame Cutting

Pure molybdenum does not cut so rapidly as iron, Wiss[25] found. He stated that 5.5% Mo added to a steel containing 8 W, 1.4 Cr, 1 C rendered the steel uncutable by the oxyacetylene cutting torch. The last statement is believed to be incorrect (private communication from Air Reduction Sales Co., October 1938).

General Observations

As a general rule, Holmberg[12] stated, molybdenum increases the creep strength and inhibits grain growth of weld-metal. Dobson and Taylor[26] confirmed Holmberg's second statement, adding that in low-carbon steel molybdenum causes "a certain amount of grain refinement in the as-welded condition." Chapman[8] believed that molybdenum has a beneficial effect on the welding arc. Three-layer V butt welds in nickel steel (3½ Ni, 0.30–0.40 C, ½ inch thick) made with 3/16 and 5/32 inch commercial covered electrodes with 0.50 Mo had the same strength as welds made with similar 3½% Ni electrodes, in Warner's[27] tests. The 0.5 Mo electrode deposited sounder weld-metal. The high strength of the weld-metal deposited by the 0.5 Mo electrode was attributed to pick up of nickel from base metal. Warner did not observe that molybdenum exerted any effect on the covered electrode arc.

The tentative A. S. T. M. standard A 206–37 T applies to seamless piping containing 0.10–0.20 C, 0.30–0.60 Mn, 0.10–0.50 Si, 0.45–0.65 Mo. Welding of defects in these pipes is permitted only when the depth of the defect does not exceed ½ the nominal wall thickness, nor is longer than 25% of the nominal pipe diameter. Chipping and

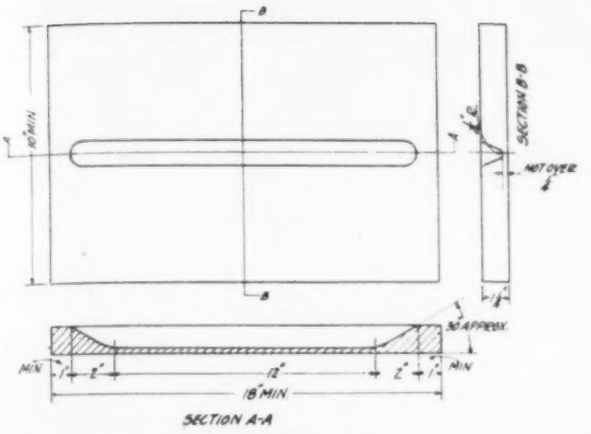

Fig. 14—Gouge Plate Used by U. S. Navy for Process Approval Tests in Welding Cast C-Mo Steel and Similar Steels for High Temperature Service. The Gouge, Which Is Prepared with Tools Identical with Those Used in Preparing Castings for Repair Welding, Simulates a Repair to Be Made by Welding and the Test Reveals Whether the Welding Practice Is Satisfactory for Finishing a Weld. Porosity or Lack of Fusion Is Detected by Splitting Along *B-B*. The Welded Plate May Be Machined to Tension, Bend and Charpy Specimens Under Some Circumstances. The Width of the Scarf Shall Be Sufficient to Yield an All-Weld-Metal Tensile Specimen 0.505 Inch Diameter. The Plate Shall Be Rigidly Clamped During Welding to Prevent Warping to an Angle of More Than 5°. No Welding on C-Mo Steel Is Permitted Below 300° F. Stewart[1]

heat treating are essential. The U. S. Navy Bureau of Engineering Process Approval Plate for arc-welded C-Mo steel, according to Stewart,[1] is identical with that used for 4–6 Cr steel (Fig. 1 of review of literature on Welding Chromium Steels, THE WELDING JOURNAL, 17(7) Suppl. (1938)). In addition a gouge plate is required for cast C-Mo steel, Fig. 4.

Vigener[28] points out that carbon-molybdenum steel boiler plate (0.5 Mo, or 0.25 Mo, 0.25 Cu) is used commonly in Germany for arc-welded and water gas-welded boilers. No difficulty has been encountered in service with welded pressure vessels of silicon-killed 0.5 Mo steel, according to Hopkins.[29] The application of C-Mo steel to ship's boilers was ruled out by Ffield,[30] because the steel requires heat treatment after welding. Schimpke and Horn[31] also recommend normalizing for arc-welded C-Mo boiler plate. It was pointed out by Harris[11] that the disadvantage of molybdenum in steel for welding is the deep hardening, which causes cracking in heavy sections. The acicular structure obtained in welds at moderate rates of cooling is lacking in ductility.

WELDING MANGANESE-MOLYBDENUM STEELS

In his studies of maximum hardness of heat-affected zone as a function of welding speed, Warner[32] deposited a bead of weld-metal 3 inches long manually on plates 3 x 9 x $^1/_2$ inch. From the results in Table 13 it may be concluded that molybdenum has little effect on hardness.

Table 13—Maximum Vickers Hardness of the Heat-Affected Zone of Mn-Mo Steels as a Function of Welding Speed. Warner[32]

	Composition of Steel					Arc Speed, Inches per Minute	
	C	Mn	Si	P	Mo	4 to 6	10 to 12
Steel No. 1	0.17	1.57	0.43	0.02	0.38	287	397
Steel No. 2	0.12	1.00	0.21	0.03	0.49	221	270

The static and tensile impact properties of 60° V butt welds are listed in Table 14. The width and parallel section of the specimens were 1 inch, and the welds were ground flush. Stress relieving was at 600° C. The organic and mineral covered electrode deposited metal containing 0.5 Mo; the core rod contained 0.13 C. In general, the welds had higher static strength than base metal, but lower ductility and impact tensile value. Stress relieving was advantageous.

Single-V butt welds made by Sommer[33] with a cored electrode 0.16 inch diameter, 150 amps. in steel 0.47 inch thick containing 0.18 C, 0.32 Si, 1.57 Mn, 0.61 Mo had a tensile strength of 90,000 lb./in.^{2} in the form of bars machined to 0.39 x 1.18 inches. Chapman[34] recommended a steel containing 0.18 C max., 0.9–1.0 Mn, 0.40–0.50 Mo for welded construction, and a similar steel (0.13 C, 0.91 Mn, 0.17 Si, 0.016 P, 0.017 S, 0.51 Mo) was used for the arc-welded underframe of a Diesel locomotive, according to Cone.[35] Some of the welds were Unionmelt; otherwise electrodes having about the same composition as base metal were used. The Royal Dutch Marine[36] used a steel containing 0.20 C max., 0.7 Si, 1.2 Mn, 0.4 Cu, 0.10 Mo in the construction of a welded cruiser. According to Deppeler,[21] satisfactory thermit welds can be made in Mn-Mo steel rails (no details). The Committee on Low Alloy Steels[37] classed steels with 0.15–0.22 C, 0.88–1.59 Mn, 0.09–0.44 Si, 0.22–0.34 Mo as moderately air hardening. Cast steels containing 0.25–0.35 C, 0.9–1.25 Mn, 0.25—0.35 Mo are suited for resistance welding into larger assemblies, according to Schröder.[38]

WELDING NICKEL-MOLYBDENUM STEELS

A rod containing 0.11 C, 0.47 Mn, 0.17 Si, 0.009 P, 0.019 S, 2.03 Ni, 0.13 Mo was used by Stursberg[39] for making V butt welds in a plate 0.24 inch thick containing 0.35 C, 0.65 Mn, 0.18 S, 0.033 P, 0.034 S. As the mixture ratio (ratio of oxygen to acetylene by volume) increased, Table 15, the tensile strength decreased and the notch impact value increased. A mixture ratio of 1.0 with root bead gave the best all-around results. Annealing increased the notch-impact value. The effect of mixture ratio doubtless is related to the carbon content of the weld-metal. With a mixture ratio of 0.8 the hardness was 415 Brinell, at 0.95, 220 Brinell, at 1.0,

Table 14—Static and Impact Tensile Properties of Arc-Welded Mn-Mo Steels $^1/_2$ Inch Thick (Coated C-Mo Electrode). Warner[32]

	Steel No. 1*				Steel No. 2*			
	Base Metal		Weld		Base Metal		Weld	
	As-Rolled	Stress Relieved	As-Welded	Stress Relieved	As-Rolled	Stress Relieved	As-Welded	Stress Relieved
Yield strength, lb./in.^{2}	36,000	47,000	55,800	....	37,000	36,500	51,600	50,000
Tensile strength, lb./in.^{2}	104,000	92,000	94,870	93,300	84,000	80,000	85,600	83,800
Elongation, % in 1 inch	42	46	22	37	54	51	30	38
Tensile impact value, ft.-lb.	890	800	614	704	780	800	712	788

* See Table 9.

Table 15—Mechanical Properties of Oxyacetylene Welds Made with Ni-Mo Rods. Stursberg[39]

	Mixture Ratio = 0.95			Mixture Ratio = 1.0			Mixture Ratio = 1.1		
	As-Welded	Root Bead*	Annealed†	As-Welded	Root Bead*	Annealed†	As-Welded	Root Bead*	Annealed†
Tensile strength, lb./in.²	88,000	83,000	78,000	83,000	80,000	73,000	76,000	73,000	73,000
Bend elongation, % in 0.59 inch	17.6	23.3	30.3	24.7	35.0	38.6	22.3	30.9	34.0
Notch-impact value, mkg./cm.²	4.53	7.27	7.94	5.45	8.63	9.42	5.77	8.80	10.1

* Root reverse welded.
† Annealed in furnace above Ac_3.

Table 16—Notch Impact Value of Arc-Welded Ni-Mo Steel at Different Temperatures. Polkowski[41]

Temperature of Test, ° C.	17	150	400	500	600	733	800	850
Unwelded	3.89	8.33	8.05	4.6	12 to 35	26.2	32.3	...
Welded	3.61	7.03	4.3 to 5.6	3.0 to 4.1	5 to 20	15 to 22	12.6	8.5 to 16.1

170 Brinell and at 1.6, 160 Brinell. The Ni-Mo rod was not so satisfactory as a rod containing 0.11 C, $3^1/_2$ Ni, 0.7 Cr.

Warner[40] found that covered electrodes with $^1/_4$% Mo had smooth arcing characteristics and produced sound weld-metal in $3^1/_2$% Ni steel. The arc welding characteristics of a steel containing 0.07 C, 0.14 Si, 0.34 Mn, 0.015 P, 0.012 S, 1.86 Ni, 0.20 Mo (for truck wheels) was reported by Polkowski[41] to be excellent. The notch-impact value of arc welds in this steel (no details) are listed in Table 16. Hoffmann[42] recommended a Ni-Mo-Mn steel (0.3 C, 0.2–0.3 Si, 1.0–1.5 Mn, 1.0–1.5 Ni, 0.25–0.3 Mo, 0.025 S, 0.03 P) for aircraft sheet and tubing to be welded with a rod containing 0.1 C, 0.1 Si, 0.5–0.6 Mn, 2 Ni, 0.17–0.18 Mo, 0.025 P, 0.03 S. The weld contained 0.04 C, 1.7–1.8 Ni, 0.1 Mo.

WELDING NICKEL-CHROMIUM-MOLYBDENUM STEELS

All-weld-metal containing 1 Ni, 0.75 Mo, 0.25 Cr deposited in a Cromansil plate 1 inch thick, according to Chapman,[8] had a yield strength of 72,000 lb./in.², tensile strength = 88,000 lb./in.², 24% elongation in 2 inches, 38% elongation in free-bend test (no details). Harris[11] pointed out that Ni-Cr-Mo steels capable of air hardening are frequently incapable of resisting the internal stresses resulting from the volume changes during welding. Welding cracks are often found. The welds require heat treatment.

R. Smallman-Tew reports (private communication, May 1938) that a single bead of fluxed alloy steel electrode deposited on an annealed steel containing 0.26 C, 2.64 Ni, 0.50 Cr, 0.55 Mo, 0.38 Mn, 275 Brinell, created the maximum hardness shown in Table 17. Only

Table 17—Maximum Hardness in Heat-Affected Zone of Ni-Cr-Mo Steel Adjacent to Single-Layer Deposited by a Fluxed Electrode. R. Smallman-Tew

Preheating Temperature, ° C.	Maximum Brinell Hardness in Heat-Affected Zone	Structure of Hardened Zone
None	509	Martensitic
150	415	Fine sorbite
250	395	Fine sorbite
350	391	Fine sorbite

relatively low preheating temperatures are required to prevent the appearance of martensite.

Hoffmann[43] praised the welding qualities of steels containing 0.3–0.8 C, 0.8–1.3 Mn, 0.8–1.0 Cr, 2–4 Ni, 0.2–0.8 Mo, but there are very few who will agree with him. Chadwick[44] recommends stress relieving for 4 hr. at 650° C. for welded cast steel containing 0.30 C, 0.43 Mn, 0.23 Si, 1.87 Ni, 0.82 Cr, 0.23 Mo.

The static and impact tensile properties of heat-treated flash and resistance butt welds in a steel containing 0.30 C, 2.5–2.8 Ni, 0.6–0.8 Cr, 0.25–0.35 Mo (Steel I, Table 57 of the review of literature on Welding Chromium Steels, THE WELDING JOURNAL, **17**(7) SUPPL. 36, July 1938) were determined by Galibourg and Ballay.[45] The flash welds had high static and impact strength and ductility after being oil quenched from 850° C. and air cooled from 625° C. The resistance butt welds were lacking in ductility.

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SUGGESTED RESEARCH PROBLEMS

1. In view of the good properties of carbon-molybdenum steels at elevated temperatures, a systematic study of the creep properties of welds in these steels should be made. The data in the review, while indicative of good creep resistance of these welds, nevertheless are very meager and incomplete.

2. Due to the increasing use of ferromolybdenum in electrode coatings, and its stated beneficial effect on arc stability and recovery, further studies of these factors might well be made. What is the mechanism of this improved arc stability, and is it present to the same degree when the molybdenum is present in the coating as when present in the electrode wire?

3. There is much conflicting opinion as to the degree of air hardening and loss of ductility and creep strength, if any, that takes place upon welding carbon-molybdenum steel without preheating, and there are still some who are skeptical of the need for preheating. A research project on this question would be of value.

DEVELOPMENT of WELDING ELECTRODES

Especially for Steel Construction*

By DR. ING. K. L. ZEYEN, VDI†

THE following is a report on Krupp research in so far as it concerns welding in steel construction.

(A) THE INFLUENCE OF THE CHEMICAL COMPOSITION OF THE WELD MATERIAL ON ITS (DESIRABLE) PROPERTIES

Table 1 shows how different the quality of a welded seam can turn out with one and the same welding wire; depending on whether it is used for gas welding or electric arc welding, not coated, or with medium or heavy coating. If we compare the properties of specimens of weld material thus obtained, especially elongation and impact strength which recently have been considered most important, we find the following conditions (none of the specimens were heat treated after welding).

The gas-welded samples showed 18.5% elongation and 11.8 mkg./cm.² impact strength. The specimens welded electrically with bare electrodes showed only 7.5% elongation and 1.5 mkg./cm.² impact strength. The values with lightly coated electrodes were not much better, namely, 11.2% elongation and 1.9 mkg./cm.² impact strength. Medium coated electrodes showed 15% elongation and 6.1 mkg./cm.² impact strength, while the heavily coated electrodes which released a protective gas produced very high values, 25% elongation and 9.6 mkg./cm.² impact strength.

The explanation for this great difference may be found in the chemical composition of the weld proper. The contents of carbon, silicon and manganese show considerable variation in the different specimens because these components were more or less oxidized during the melting of the welding wire under the various conditions. But the quantities of nitrogen and oxygen taken up by the material of the weld are still more important than the just mentioned substances. In perfect agreement with other test results published recently it is found that the impact strength decreases with increasing oxygen and nitrogen contents. As will be shown later, the nitrogen is more important, even though the numerical values of the nitrogen contents are considerably lower than those of the oxygen contents. If we compare the physical properties of weld material electrically welded with bare and heavily coated electrodes producing protective gases, respectively, we find in the first case that with 0.140% nitrogen and 0.210% oxygen only 7.5% elongation, 17% reduction of area and 1.5 mkg./cm.² impact strength could be measured. In the latter case, however, with 0.013% nitrogen, 0.099% oxygen several times the above values, namely, 25% elongation, 47% reduction of area and 9.6 mkg./cm.² were produced.

(B) IMPROVEMENT OF THE TOUGHNESS (DUCTILITY) OF A WELDED SEAM BY HEAT TREATMENT DEPENDS ON ITS OXYGEN AND NITROGEN CONTENTS

Up to now the possibility of subsequent heat treatment of welds has probably hardly been considered and much less applied. But it may be said that no doubt heat treatment of welds will be applied in the future at least in some special cases. For that reason we should like to show by means of a few examples (see Tables 2 to 4) from the test series mentioned before, that the possibility of thus improving a weld depends to a large extent on its nitrogen and oxygen contents.

* Extended abstract of "Uber Forschungsarbeiten zur Entwicklung von Schweisselektroden, insbesondere für den Stahlbau" published in *Stahlbau, Hefi* **6**, 7/8, 1938. Translated through the courtesy of Detroit Edison Company. Paper read before the German Committee for Steel Construction in Munich, December 10, 1937.

† Messrs. F. Krupp, A. G., Essen, Germany.

Table 1—Change in the Chemical Composition of a Welding Electrode and the Physical Properties of Specimens of Weld Material

	Chemical Composition					Mechanical Properties					
Material	C, %	Si, %	Mn, %	N_2, %	O_2, %	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation % $l = 5d$ %	Reduction of Area %	Notched Bar Impact Strength (DVMR Specimen) Mkg./Cm.²	Brinell Hardness
Electrode wire	0.13	0.07	0.66	0.005	0.021	...	...	...	...	...	...
Weld material, gas welded	0.10	0.02	0.49	0.017	0.037	36,100	56,600	18.5	38	11.8	113
Weld material, arc welded with D.C. (bare electrode)	0.03	0.02	0.20	0.140	0.210	43,800	59,500	7.5	17	1.5	135
Weld material, arc welded with D.C. (lightly dipped electrode)	0.04	0.02	0.20	0.120	0.180	42,400	67,900	11.2	21	1.9	129
Weld material, arc welded with D.C. (medium coated electrode)	0.04	0.04	0.25	0.079	0.140	43,800	62,400	15.0	30	6.1	131
Weld material, arc welded with D.C. (coated electrode producing protective gases)	0.06	0.07	0.36	0.013	0.099	46,600	66,700	25.0	47	9.6	140

Table 2—Arc Welding with Negative Bare Electrodes. Nitrogen Contents of Samples 0.14%

	a Not Heat Treated	*b* Normalized ½ Hour 900° C. Aircooled	*c* Annealed 2 Hours 600° C. Aircooled
Yield strength, lb./in.²	43,800	39,500	39,500
Tensile strength, lb./in.²	59,500	59,500	56,600
Elongation % ($L = 5d$)	7.5	9.5	7.5
Reduction of area, %	17	23	14
Notched bar impact strength mkg./cm.² (DVMR specimen)	1.5	1.4	1.9
Brinell hardness	135	125	119

Table 3—Arc Welding with Medium Covered Positive Electrode. Nitrogen Contents of Samples 0.079%

	a Not Heat Treated	*b* Normalized ½ Hour 900° C. Aircooled	*c* Annealed 2 Hours 600° C. Aircooled
Yield strength, lb./in.²	43,800	41,000	39,500
Tensile strength, lb./in.²	62,400	58,000	58,000
Elongation % ($L = 5d$)	15	16	16
Reduction of area, %	30	28	27
Notched bar impact strength mkg./cm.² (DVMR specimen)	6.1	5.6	5.7
Brinell hardness	131	127	119

Table 4—Arc Weld with Heavily Coated Positive Electrode, Coating Producing Protecting Gas. Nitrogen Contents of Samples 0.013%

	a Not Heat Treated	*b* Normalized ½ Hour 900° C. Aircooled	*c* Annealed 2 Hours 600° C. Aircooled
Yield strength, lb. /in.²	46,700	46,700	50,800
Tensile strength, lb./in.²	66,600	65,900	68,500
Elongation % ($L = 5d$)	25	26	28
Reduction of area, %	47	49	59
Notched bar impact strength mkg./cm.² (DVMR specimen)	9.6	9.9	10.4
Brinell hardness	140	131	127

(C) WELDING MATERIALS FOR STEEL CONSTRUCTION

In the last few years a definite change could be observed in most countries from cheap welding wires which produced comparatively low-grade welds to high-grade welding rods. Table 5, for example, shows that in the U. S. A. the quantity of uncoated electrodes which was still 26.7% in 1933 has decreased to 15.3% of the total production in the first half of 1935. In the quantity of lightly coated electrodes, a similar decrease can be found. During the same time, on the other hand, the quantity of heavily coated electrodes—which produce high-grade welds—has increased from 32.6 to 57.7%.

Table 5—Manufacture of Welding Electrodes in the U. S. A. According to J. Muller

	Distribution in %		
Type of Electrodes	1933	1934	First Half of 1935
Bare for manual welding	26.7	20.3	15.3
Bare for automatic welding	5.2	3.3	4.0
Dust coated	15.2	14.9	12.0
Standard coated	14.2	7.8	5.9
Heavy coated	32.6	47.7	57.7
For alloyed steels with up to 1.25% alloy components (besides Fe and C)	2.5	2.1	2.2
For alloyed steels with more than 1.25% alloy components (besides Fe and C)	3.4	3.2	2.1
For alloyed steels with more than 3% Cr	0.1	0.7	0.7

(*The Weld. Eng.*, **21**, 1936, No. 1, p. 30).

A similar development can be noticed in the welding departments of Messrs. Krupp during the past few years.

Especially in structural steel work heavily coated electrodes are today used here almost exclusively.

(D) TOUGHNESS IN NOTCHED BAR IMPACT TEST OF WELDS AT TESTING TEMPERATURES BETWEEN 70 AND 400° C.

We should like to report first on some tests made to determine the impact strength in welds without implying, however, that we consider the notched bar impact test as the most important criterion for the quality of welds. Plates of mild steel I, 12 mm. thick were butt welded with various electrodes. From these welds

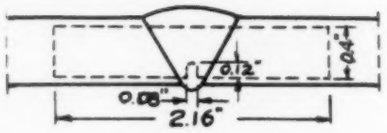

Fig. 1.—Notch-Impact Specimen in 60° V Butt Weld

impact specimens were cut in such a way that the weld was in the middle of the specimen, and the notch at the root of the V cut. Figure 1 shows the layout and the dimensions of the impact specimens. These specimens were tested in the temperature range from −70 to +400° C. Figure 2 shows the values obtained with different electrodes. The behavior of the various curves is similar in so far as the maximum value of the impact strength in the weld lies between +20 and +200° C. in all cases. The strength drops rapidly toward lower temperatures and somewhat less rapidly toward higher temperatures. The various electrodes show different behavior not only in the absolute values of the strength they produce, but also in the appearance of the descending branches of the curves. The two lower curves refer to uncoated (curve *A*) and slightly coated (curve *B*) electrodes of the government railway grade E 37 (preliminary standard DIN 1913, grades E 37 and E 42). In the temperature range between +50 and +200° C. the impact strength produced with these electrodes is between 3 and 4 mkg./cm². Already at 0° C. these values decrease to half this value and at −20° C. they are only about 1 mkg./cm².

The third curve from the bottom (*C*) refers to an alloyed electrode with core—not the same as that described by Leitner (*Z. VDI.*, **80,** 851 (1936)), and by Hackert and the author (*Techn. Mitt. Krupp*, **5,** 22 (1937))—but to a later development. This new electrode has been admitted by the government railways to their grade classification *E* 52. According to our investigations the impact strength produced with this electrode is about 7 to 9 mkg./cm.² in the temperature range between +20° and +200° C., that is, about twice that produced with uncoated or lightly coated electrodes, or with unalloyed electrodes with core. But here also the impact strength is rather low at 0° C., and at −50° C. it has decreased to 1.5 mkg./cm². The fourth curve from the bottom (*D*) refers to a medium coated electrode much used for structural steel (government railway classification *E37h* and *E52h*). At testing temperatures between +50° and +100° C. this electrode produced an impact strength above 11 mkg./cm.², but still a rapid drop toward lower temperatures, so that the impact strength of the weld was only a little over 6 mkg./cm.² at −50° C. and 1.5 mkg./cm.² at − 70° C.

The top curve (*E*) refers to a coated electrode as it is usually used by Messrs. Krupp for the welding of steel structures (government railway grade *E34h*, *E37h*, *E52h*). Among other jobs this electrode was used for the bridge across the Strela Sound and for the two latest Rhine bridges. At temperatures between +20° and 100° C. this electrode produced an impact strength in the weld of about 13 mkg./cm.² Contrary to all other electrodes discussed so far this one still showed an impact strength of about 5 mkg./cm.² at a testing temperature of −70° C. Similar results but more of the order of curve *D*, also obtained with a coated electrode, have recently been reported by H. Aysslinger, P. Jessen and W. Stöckmann.[1]

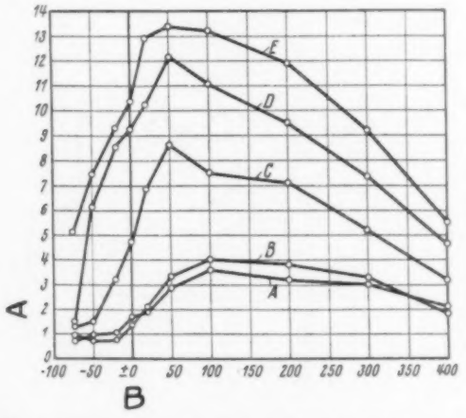

Fig. 2—Notch-Impact Value of Arc-Welded Butt Welds with Different Types of Electrodes in Mild Steel 0.47 Inch Thick

A = notch-impact value, DVMR specimen, mkg./cm.²
B = test temperature, ° C.
A = bare electrode
B = lightly dipped electrode
C = alloyed electrode with core
D = medium covered electrode
E = normal covered electrode

(E) INFLUENCE OF HEAT TREATMENT ON THE IMPACT STRENGTH OF WELDED SEAMS MADE WITH COATED ELECTRODES AND ALLOYED ELECTRODES WITH CORES

We should like to discuss now a little more in detail these two electrodes which seem most important for

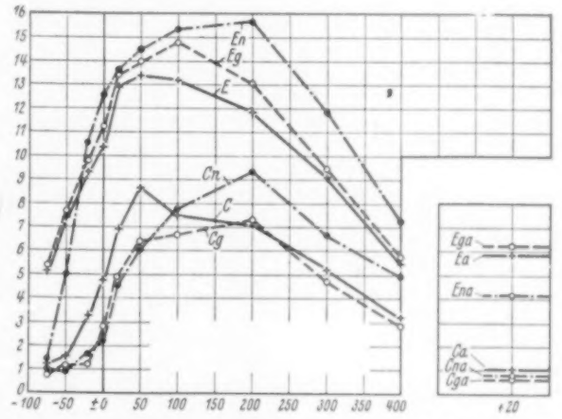

Fig. 3—Notched Bar Impact Strength in Electrically Welded Butt Welds, Using Covered Electrodes and Alloyed Electrodes with Core. (Plates of Mild Steel I, 12 Mm. Thick)

A = notch-impact value, mkg./cm.², DVMR specimen
B = test temperature, ° C.
C = alloyed electrode with core
E = normal coated electrode
Small diagram at right refers to welds that have been aged

structural steel today, the alloyed electrode with core and the normal coated electrode, both in their most recent form. The corresponding curves in Fig. 2 are marked *C* and *E*. It is quite interesting to see how the temperature impact characteristics are changed by heat treatment in the case of these two electrodes. The results of these tests are of interest for structural steel welds because some day heat treatment will be applied to them, at least in some special cases. Another problem, the preheating of structural parts before welding, will be discussed later. Figure 3 shows the curves of the impact strength of welds before and after heat treatment. The solid curves *C* and *E* in this case are the same as those in Fig. 2. They refer to the alloyed electrode with core (*C*) and the coated electrode (*E*) before heat treatment of the weld. Curves *Cg* and *Eg* (broken line) show the effect of stress relieving (2 hours at 600° C., furnace) and curves C_a and E_a (dots and dashes) that of

normalizing heat treatment ($^1/_2$ hour 900° C., Air Cooled). The curves show the following: In the specimens which were not heat treated the absolute values of the impact strength of the welds with coated electrodes (*E*) is in all cases considerably higher than that obtained with alloyed electrodes with core (*C*). In the case of the coated electrode, stress relieving still further increased these values at all temperatures (curve *Eg*). At temperatures between −20° and +200° C. normalizing treatment increased the impact strength even beyond that of the untreated or stress-relieved specimen (curve E_n). However, at testing temperatures between −50 and −70° C. the impact strength of the normalized specimens welded with the coated electrode fell off considerably. Similar results were obtained with coated electrodes by J. Quadflieg.[2]

In the case of the alloyed electrode with core the impact strength of both normalized and stress-relieved specimens was lower between +50° and −70° than that of the untreated specimen. Between +100° and +400° C. the normalizing treatment (*Cn*) produced an increase in the impact strength over that of the untreated specimen, but stress relieving brought no improvement of any kind (*Cg*).

(F) IMPACT STRENGTH OF WELD AFTER AGING

At the right of Fig. 3 a few values are shown for aged impact test specimens. The aging process consisted of 10% upsetting followed by 30 minutes heating to 250° C., and it was applied to samples which were not heat treated as well as to some that had been stress relieved or normalized, respectively. For the alloyed electrode with core the impact strength of the thus aged weld specimens lies at only 1 to 0.5 mkg./cm.^{2} while for the coated electrode it lies between 4 and 6 mkg./cm.^{2}

One might ask whether mechanical aging of welds was at all important in welded steel structures. In his dissertation W. Kleinefenn[3] has stated that this problem is important for all kinds of welds because in a weld produced by the melting of metal subsequent shrinkage may produce cold working of the weld as well as of the base material. Similar conditions were described by J. Quadflieg.[4] Tests with aged weld specimens are therefore of more than mere academic interest.

Table 6—Chemical Composition of Weld Material

Type of Electrode	C, %	Si, %	Mn, %	P, %	S, %	N_2, %	O_2, %
Coated electrode (*E*)	0.10	0.08	0.50	0.025	0.030	0.026	0.094
Alloyed electrode with core (*C*)	0.09	0.04	1.17	0.024	0.021	0.110	0.048

(G) THE NITROGEN IN THE MATERIAL OF THE WELD EXPLAINS WHY THE ALLOYED ELECTRODE WITH CORE AND THE COATED ELECTRODE CAUSE SUCH DIFFERENCE IN THE RESULTS OF HEAT TREATMENT OF WELDS

Just as it did in the tests earlier described, the chemical composition of the weld material showed why alloyed electrodes with core, and coated electrodes, behave so differently as far as aging is concerned. Table 6 shows a compilation of the analyses of weld material made with the two electrodes.

The nitrogen contents of 0.11% produced with the alloyed electrode with core prevented improvement by heat treatment generally for test temperatures up to +50° C., and in most cases even for higher test temperature. On the other hand weld material produced with the coated electrode contained only 0.026% N_2 and it could be improved by heat treatment almost without exception. In the case of the electrode with core the low values of the aged samples must also be explained as due to the nitrogen contents. Because the oxygen contents of the weld material from the electrons with core is considerably below that produced by the coated electrodes it is shown that nitrogen in a weld is really much more important (for weakening it) than oxygen.

(H) ARE THERE ANY RELATIONS BETWEEN IMPACT STRENGTH AND BENDING ANGLE IN A WELD?

The tests just discussed are only a few out of a long investigation still proceeding on impact strength, bending angle and fatigue strength of welds made by different methods and with different welding wires. One purpose of the investigation is to find how much any of the tested properties considered most important today are in any way related. Table 7 shows for mild steel I, welded with different electrodes, the impact strength of the weld material at +20° C., the bending angle around a pin, and the free bending angle with unma-

Table 7—Bending Angles of Electric Butt Welds. Sheets of Mild Steel I, 12 Mm. Thick

Type of Electrode Used	Heat Treatment of Specimen After Welding	Notched Bar Impact Strength in the Weld, Mkg./Cm.^{2} at +20° C. (DVMR-specimen)	Bending Angle in Degrees, Bead Undisturbed: Bent Around a Pin	Bead Undisturbed: Bent Free	Bead Machined Off: Bent Around a Pin	Bead Machined Off: Bent Free
Bare (*A*)	None	2.0	61	78	22	53
Lightly dipped (*B*)	None	2.1	65	114	45	91
Alloyed electrode with core (*C*)	None	6.85	89	118	151	154
	Annealed	4.8	110	120	135	>180
	Normalized	4.5	180	180	83	180
Medium covered electrode (*D*)	None	10.3	180	180	>180	>180
	Annealed	10.5	180	180	>180	>180
	Normalized	10.6	180	180	>180	>180
Normal covered electrode (*E*)	None	12.9	180	180	>180	>180
	Annealed	13.5	180	180	>180	>180
	Normalized	13.65	180	180	>180	>180

chined and with machined bead. The values are quite informative. The bending tests show that the bending angle of the free-bending test is consistently greater than that obtained around a pin. A relation between the impact strength of the weld material and the bending test exists only in so far as the lowest impact strength of the non-heat-treated specimens corresponds with the lowest bending angle. At higher impact strength the bending test does not differentiate any more. It is found that in all cases in which the impact strength is 10 mkg./cm.^{2} and higher a 180° angle of bend can be produced with or without cracking, respectively. In the heat-treated samples the bending angle always rises above that of the non-heat-treated specimens, if it is not already 180° in the latter case. But as the samples welded with alloyed electrodes with core show, the same heat treatment which increases the bending angle simultaneously reduces the impact strength of the weld.

Table 8—Limits of Analysis of Weldable Structural Steel St52 Laid Down by the German Government Railways

C maximum 0.20%	In addition to this
Si maximum 0.50%	Mn up to 0.3%
Mn maximum 1.20%	or Cr up to 0.4%
Cu maximum 0.55%	or Mo up to 0.2%
P maximum 0.06%	
S maximum 0.06%	
P and S total maximum 0.10	

(I) HARDENING OF STEELS BY THE WELDING HEAT, AND TENDENCY TO CRACK FORMATION IN THE WELD

The mention of welding cracks touches a subject which cannot be ignored in this review. In a number of failures due to cracks in the welds which appeared during 1936 in welds made with coated electrodes, particularly in steel St52, it was found that with certain base materials normal coated electrodes might fall down. It had been known for some time (previously reported by the author)[4] that in plain carbon steels beyond a certain carbon content, normal coated electrodes caused thermal cracks, especially in fillet welds. The limitation of the alloying elements in weldable structural steel St52 put through by the government railways in 1936 was intended not only to avoid the tendency to cracking in the welds, but also to avoid excessive hardening of the base material in the neighborhood of the welds (see Table 8).

The problem of hardening of a steel by welding heat is in itself nothing new, especially in steel St52. In shipbuilding the problem appeared a number of years ago when it was attempted to assemble plates of steel St52 to very large sheets. In order to correct the warping and bulging which appeared in very large sheets assembled by welding, due to thermal stresses, the necessary places were heated to red heat with an oxyacetylene torch and then more or less rapidly chilled. It was found that among the then available steel types St52 especially could not stand such severe treatment and that they were very much hardened. Table 9 shows the results of tests to develop an St52 structural steel, published by A. Fry[5] in 1933; this steel was supposed to withstand such mistreatment. It may be seen that two structural steels St52 with almost identical static strength but different analyses, showed very different toughness and ductility after chilling from 1020° C. in water. In this particular case the toughness or ductility was tested by bending. Table 10 gives some data from very extensive tests made by Messrs. Krupp in 1932 for the purpose of developing an St52 structural steel which would be hardened as little as possible by welding heat in the zones adjacent to the weld. Even at that time it was entirely clear to us that the attainment of this goal was important not only for the already mentioned special case in ship-building, but in general for the application of structural steel St52 to welding. Finally, in Fig. 4 we show the results of different welding and quenching tests with an St52 structural steel showing the least tendency to hardening according to our experiments. It is characteristic that the mechanical properties of this composition change very little with different welding and chilling treatment. Based on the above mentioned tests Messrs. Krupp specified the corresponding analysis of their structural steel St52 as early as 1932, and it should be noted that the analysis then specified fits completely within the limits decreed in 1936 by the government railways for weldable steel St52.

Table 9—Sensitiveness to Quenching of Low-Alloy Structural Steels St52 of About the Same Strength but Different Composition

Material A		Material B
Yield point, kg./mm.^{2}	40.7	40
Tensile strength, kg./mm.^{2}	58.7	56.9
Elongation, % $l = 5.65\sqrt{f}$	29.5	28.1
Bending angle at first cracking after quenching from 1020° C. in water		
0.24 Inch plate	180°	170°
0.47 Inch plate	140°	100°
0.71 Inch plate	110°	50°

G. Bierett[6] has recently shown that the tendency to crack formation due to hardening of a steel in the zones adjacent to a weld depends considerably on the welding

Table 10—Tests Concerning Sensitiveness of Low-Alloy Structural Steels St52, Made in 1932

Chemical Composition								Mechanical Data, Plates 0.47 Inch Thick (Normalized)				Brinell Hardness After Quenching			
												From 920° C.		From 1020° C.	
C, %	Si, %	Mn, %	Cu, %	Cr, %	Ni, %	Mo, %	V, %	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, % $l = 11.3\sqrt{f}$	Brinell Hardness	1 Second in Water	Completely in Water	1 Second in Water	Completely in Water
0.13	0.39	1.07	0.41					55,600	72,400	22.1	154	152	333	149	325
0.13	0.55	1.31	0.42	0.15				61,700	84,600	24.0	156	154	350	156	325
0.15	0.56	1.24	0.43		0.15			56,700	82,200	21.2	151	168	333	155	306
0.14	0.55	1.30	0.42			0.10		76,800	101,000	18.7	167	164	309	169	325
0.14	0.40	1.24	0.41				0.17	55,900	87,500	21.1	160	187	341	206	333
0.19	0.53	1.24	0.41					63,300	88,500	22.0	160	167	378	169	333
0.15	0.60	1.72	0.40					55,900	109,000	18.5	172	186	363	176	337
0.20	0.63	1.77	0.41					69,500	121,000	12.8	191	198	393	201	345

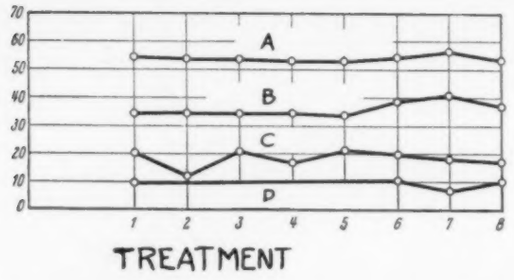

Fig. 4—Mechanical Properties of Low-Alloy Structural Steel St52 (Special Grade With Very Low Sensitiveness to Chilling) After Different Kinds of Treatment. Thickness of Plate = 0.58 Inch

A = tensile strength, kg./mm.²
B = yield point, kg./mm.²
C = elongation, %
D = notched bar impact strength, mkg./cm.²

Treatment 1 = Plate in unwelded condition.
" 2 = Plate V butt welded (bare electrodes), reinforcement machined off.
" 3 = Plate with bead applied and then machined off.
" 4 = Plate with 1/2-inch strap welded on, two light fillet welds, later machined off.
" 5 = Same as 4, but with heavy fillet welds.
" 6 = Plate cooled from 900° C. in quiet air.
" 7 = Plate quenched in oil for 10 seconds.
" 8 = Plate quenched in water for 1 second.
Bending angle in cases 1, 6, 7 and 8 greater than 180°.

procedure in addition to depending on the composition of the steel, and that this tendency decreases with increasing electrode diameter and with preheating of the base material. The findings of W. G. Theisinger[7] are of similar nature; with carbon steels of 0.17 to 0.53% C he found that with increasing welding speed or with decreasing thermal energy the hardness rises more in the zone adjacent to the weld. As was to be expected the rise is the higher the greater the C-contents of the base material, and the more rapid the cooling.

We should like to point out here a remarkable new method for the testing of the hardness increase of steels due to welding which has been suggested by H. Hauttmann[8] before this year's convention of the German Association for Testing Materials at Düsseldorf. In principle the method consists in making an etched polished specimen of a weld and rolling a small ball of about 1/16 inch diameter over it with constant pressure of 15 kg. and given velocity of 1/2 m./sec. The path of varying width caused by the ball in zones of different hardness is then measured with a microscope.

In the course of a cooperative project of the (German) Society of Metallurgists, the results of which have not yet been published, it was found that by welding steel St52 at a few 100° C. preheat, considerably higher bending angles could be produced than when the base material was welded cold. Messrs. Friedrich-Albert-Hütte have therefore provided for making particularly important welds of St52 steel in the near future after preheating of the prepared joint to about 200° C. The device specially developed for this purpose makes it possible not only to maintain this temperature during welding, but it also protects the welder against radiant heat. It is important for such cases to know the impact strength of the weld at about 200° C., and the published figures give sufficient data for this. As the curves show, the notched bar impact strength at a temperature of about 200° C. is very good throughout.

Besides a reduction of the tendency to harden in the zones adjacent to the weld with consequent danger of cracking in this zone, the German government railways also intended to avoid the danger of cracks in welds made with normal coated electrodes when they set upper limits for the analysis of weldable St52 steel.

C. Stieler[9] defined "Schweissnahtrissigkeit" as the formation of longitudinal and transverse cracks in welded seams, especially in fillet welds, during their cooling. We stated at the same time, that the usual blue tempering color of these cracks does not justify the conclusion that they were produced in that temperature range; that they probably began above that temperature. The fact that such fractures are hardly ever observed in the case of uncoated electrodes and electrodes with cores is explained by Stieler by the fact that with such electrodes the bead is built up more, and that it can therefore withstand higher stresses than for example a fillet weld made with a coated electrode. Stieler indicates further that the welded base material seems to have great influence on the cracking of fillet welds and that, according to findings of the German government railways steel St52 with high Si contents particularly tends to crack in fillet welds made with coated electrodes. In order to test the tendency of an electrode to produce welding cracks the German government railways use T-shaped samples on which the second fillet weld is made so rapidly after the first that the first is still hot. In the case of electrodes tending to crack, the second weld cracks open under these circumstances. The investigation of the German government railways made in 1936 showed that among the then available and permissible coated electrodes there were a number which caused failure with St52 steel of the composition then used, and some even caused failure with steel St37. The industry manufacturing welding electrodes has been able to eliminate these failures, even though purely empirically and without being able to explain why, a normal coated electrode fails one time and does not another time.

Table 11—Investigation of Coated Electrodes According to C. Stieler

Coated electrode No.		1	2	3	4	5
Admitted for German railway classification		*E34h* to *E52h*	*E34h* to *E53h*	*E37h* to *E52h*	*E34h* to *E52h*	*E34h* to *E52h*
Appearance of fillet weld specimen		Some cracks	No cracks	Many cracks	No cracks	No cracks
Chemical composition of weld material	C, %	0.11	0.10	0.14	0.10	0.10
	Si, %	0.04	0.03	0.03	0.04	0.03
	Mn, %	0.55	0.50	0.58	0.43	0.32
	P, %	0.046	0.046	0.071	0.035	0.033
	S, %	0.029	0.029	0.035	0.030	0.039
	Cu, %	0.14	0.14	0.13	0.12	0.15
	Ni, %	0.05	0.04	0.05	0.05	0.04
	Cr, %	0.04	0.04	0.02	0.04	0.03
	Mo, %	0.23	0.22	...	...	Trace
	N_2, %	0.031	0.040	0.025	0.024	0.032
	O_2, %	0.150	0.140	0.140	0.140	0.130
	H, %	0.0004	0.0006	0.0006	0.0004	0.0011

C. Stieler has recently furnished new and valuable contributions to the problem of welding cracks in a paper delivered at Düsseldorf on September 10, 1937, which is published in *Stahl und Eisen*. That shrinkage stresses, the shape of the seam, and the composition of the base material all were important factors had already been known from many observations made under practical conditions. Stieler now has attempted to find a relation between the composition of the weld material and the tendency for welding cracks of an electrode. Table 11 contains a compilation of the analysis of weld material produced with satisfactory and unsatisfactory coated electrodes, according to Stieler.

Electrodes 1 and 2 are the same grade of a coated electrode. The difference is only that No. 1 showed a tendency to crack formation with St52 during tests in Wittenberge and that, therefore, the manufacturers

modified it to No. 2 which produced fillet welds free from cracks. However, just why one modification of the electrode causes cracks and the other not, is not apparent from the analysis of the welding material, and no scientific explanation can be given for the difference in the behavior of these two modifications of the same electrode. On the other hand, one may say with certainty that in electrode No. 3 which caused cracks in fillet welds of St52 as well as St37 the high C and P contents of the welding material is responsible for the failures. Attempts by Stieler to introduce sulfur into the coating of coated electrodes which in themselves did not show tendency to crack formation showed that also a sufficiently high S-content of the weld material would cause cracking. The contents of P and S which are recognized as dangerous are already so high, however, that they would never appear with a high-grade coated electrode.

G. Bierett[6] points out that the problem of weld crack tendency is extremely difficult because of the large number of factors involved, some of which cannot even be expressed numerically. Thus, it will at present be necessary to be satisfied with empirical specimens to test for tendency for welding cracks.

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REVERSED BEND FATIGUE STRENGTH of Fillet and Butt Welds*

By A. THUM and A. ERKER

THE reversed bend endurance limit (10 million cycles) of rolled steel plates 0.59 inch thick, 20 inches long butt or fillet welded at right angles to a base plate, Fig. 1, was 12,800 to 14,200 lb./in.^{2} Milling the undercut with a hand-operated formed milling cutter raised the endurance limit of the fillet welds to 19,900 lb./in.^{2} and of the butt welds to 22,000 lb./in.^{2} Every visible black spot indicative of undercut must be removed and the junction with base metal smoothed and rounded in order to secure full benefit of milling. Since stress-relieved, unmachined specimens (5 hr. at 600° C., furnace cooled) had practically the same endurance limit as untreated welds, it may be concluded that shrinkage stresses have little effect on fatigue behavior. If uniform initial compressive stress is developed in the vicinity of undercut by means of cold rolling, Fig. 2, the endurance limit of the weld is raised to 22,000 lb./in.^{2}, which is the same as unwelded plate with mill scale. Ball peening or other means of producing non-uniform initial compressive stress at the undercut is quite ineffective. Completely machined welded joints had the same endurance limit as unwelded base metal.

The tests were performed on a reversed bend fatigue machine in which an eccentric actuated the upper end of the specimen just below the natural frequency of the system (see A. Thum and G. Bergmann, 2. *Z. VDI.*, **81**, 1013 (1937)). The specimens were made of mild steel,

* Abstract of "Dauerbiegefestigkeit von Kehl- und Stumpfnahtverbindungen," published in *Z. VDI.*, **82**, (38) 1101–11, Sept. 17, 1938. The investigation is a research project of the Welding Research Committee of the VDI. By undercut, the authors mean not only the customary trough, but the general notch effect at the junction of weld with base metal.

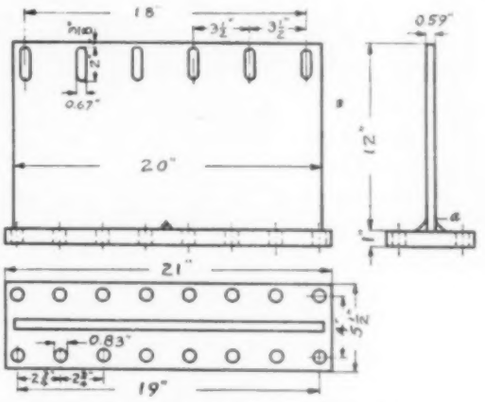

Fig. 1a—Fillet-Welded Specimens
a = dangerous section

Table 1, and were welded (D.C.) with a heavy covered electrode (0.1 C, up to 0.1 Si, 1.5 Mn).

FILLET WELDS (Fig. 1a)

The results of the tests on fillet-welded joints are summarized in Fig. 3. In the as-welded specimens cracks occurred simultaneously at several points along the junction of weld with base metal. Visible undercut, slag inclusions, porosity and notch effect on a microscopic

Table 1—Mechanical Properties of the Steel, Which Contained 0.09 C, Trace Si, 0.41 Mn, 0.012 P, 0.013 S, 0.13 Cu, 0.14 Cr, 0.10 Ni

	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation % in 3 Inches	Reduction of Area, %	DVMR Notch Impact Value, Mkg./Cm.^{2}
As-received	31,500–32,300	52,000–52,500	37.2	62–64	9.7–11.2
Heated 5 hr. at 600° C. and furnace cooled	30,200–31,200	51,600–52,000	41.4	63–67	14.8–17.9 (not fractured)
Normalized ½ hr. at 920° C.	32,000–33,200	49,500–50,500	41.7–42.0	64–67	13.0–13.9 (not fractured)

The cross section of the tensile bars was 0.59 × 0.59 inch.

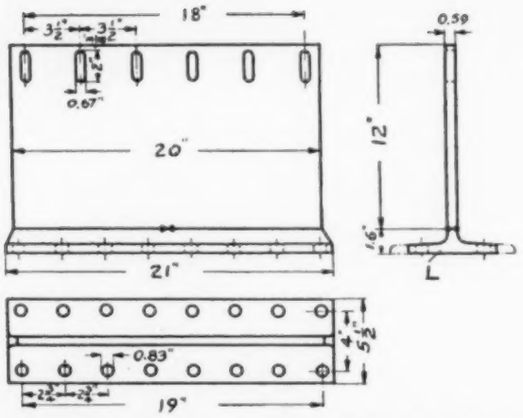

Fig. 1*b*—Butt-Welded Specimens. The Base Plate, L, Consisted of Part of a *T* Section, the Web Being About 0.63 Inch Thick at the Weld, the Flanges Also Being About 0.63 Inch Thick

scale were causes of failure. Superficial milling of the junction was ineffective. Careful milling, on the other hand, was completely effective but 3.3 ft. of weld required two hours machining. Doubtless better tools would greatly decrease the excessive machining time. The best method is to remove 0.008–0.012 inch from the vicinity of the junction by means of an abrasive stone by hand. The scratches left by the stone are parallel to the weld and must be removed by the miller, which also reveals any black spots covered by the abrasive stone. Properly machined specimens started to crack under fatigue partly at the sharpest milled groove and partly in unaffected base metal.

Although the shrinkage stresses in the specimens were not measured, it is safe to assume that the stresses attained the yield point at some points along the welds, which were made in several layers. Stress relief (5 hr. at 600° C., furnace cooled) raised the endurance limit only 16%. Superficial milling of the junction followed by peening with a ball peen hammer (radius of ball = 0.10 inch) resulting in a succession of small impressions in the milled area was ineffective in raising the endurance limit. Cracks originated at many more points along the junction than with untreated welds. The rolling machine, Fig. 2, yielded satisfactory results. The specimen is clamped to a planer bed, while the rolling device is attached to the head. The rolls, which had a radius of 0.10 inch, were passed back and forth three or four times by hand so as to obtain a smooth trace about 0.14 inch wide. The correct pressure was 1650 lb. pressures of 850 to 1100 lb. being insufficient to produce the desired result. Fracture of properly rolled specimens occurred in base metal about $^1/_2$ inch from the weld.

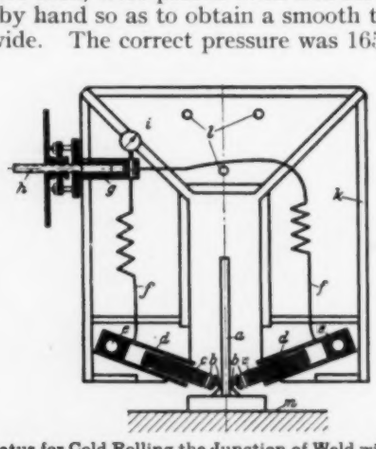

Fig. 2—Apparatus for Cold Rolling the Junction of Weld with Base Metal to Develop Uniform Initial Compressive Stresses

a—specimen
b—rollers
c—piston
d—pressure cylinder
e—pivot for cylinder
f—oil pressure tubes
g—pressure cylinder
h—piston for developing oil pressure
i—pressure gage
k—frame
l—bolt holes to fasten frame to planer head
m—planer bed

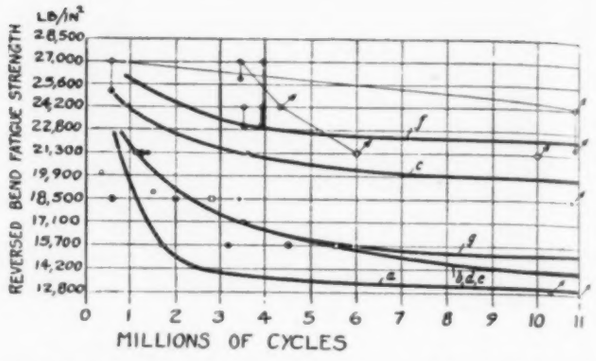

Fig. 3—Results of Reversed Bend Fatigue Tests on Fillet-Welded Joints

a: ⊙ untreated
b: □ undercut superficially milled
c: × undercut smoothly milled
d: ◉ undercut superficially milled and cold peened
e: ● undercut smoothly milled and cold peened
f: ◇ undercut rolled (curve *f* shows the fatigue strength of untreated base metal with mill scale, because fracture did not occur in weld or undercut)
f: ◆ stress at cross section of fracture
g: + stress relief annealed
The thin line joins points determined on the same type of specimen

BUTT WELDS (Fig. 1*b*)

The results with butt-welded joints are summarized in Fig. 4. Due to greater thickness, the stress in the weld was only 70% of the stress in base metal. Fracture in as-welded and machined specimens was of the same

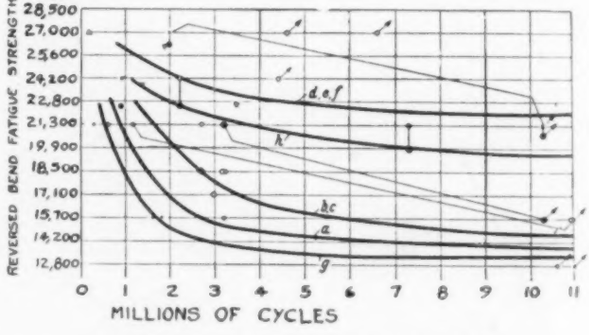

Fig. 4—Stress-Cycle Curves for Butt-Welded Joints

a: ○ untreated
b: □ undercut superficially milled
c: ◉ undercut superficially milled and cold peened
d: × undercut smoothly milled. ⊗ stress at cross section of fracture
e: ◇ undercut rolled
△ undercut cold peened
f: ▽ undercut and weld reinforcement machined flush
g: + stress relief annealed
h: ● normalized, weld forged. ◉ stress at cross section of fracture
Curves *d*, *e*, *f* show the fatigue strength of untreated base metal with mill scale, because fracture in these specimens did not occur in the weld or undercut zone. For the same reason, curve *h* shows the fatigue strength of normalized base metal. The thin line joins points determined on the same type of specimen

type as in fillet welds. Specimens in which the weld was machined flush with base metal had an endurance limit of 22,000 lb./in.², the same as base metal. Fracture occurred partly in weld-metal, partly in base metal. Stress relief did not raise the endurance limit. Several specimens were heated $^1/_2$ hr. at 920° C. at which temperature the weld was forged to about the same thickness as base metal. The specimens were cooled in air and the junction of weld to plate was milled smooth. The endurance limit was 19,600 lb./in.², fracture occurring in the plate, whose strength was decreased a little by normalizing. Hammering and cold rolling had about the same effects as in fillet welds.

THE FATIGUE STRENGTH OF Oxyacetylene Welded Rails*

By PROFESSOR OTTO GRAF†

THE pulsating bend fatigue strength of three types of rails and of oxyacetylene welded and bolted joints therein was determined during the period 1935–1937 using specimens 3.9 feet long on a span of 3.3 feet with central loading. The tensile stress in the outermost tension fiber pulsated between a maximum and 1400–2800 lb./in.² at a frequency of 250 cycles per minute. The fatigue strength criterion was 2 million cycles and all fatigue strengths quoted are based on a lower stress of zero (upper stress minus lower stress). The results are summarized in Tables 1 to 4, the composition, dimensions and tensile properties of the rails being given in Table 5.

The welded joints, Figs. 1 and 2, were of the Holler type prepared by a commercial firm according to best practice. It has been shown that rails with butt-welded heads but with fillet-welded straps on both sides are not satisfactory (Graf, O., *Stahlbau*, 1937, p. 9; and *Arcos*, 1934, p. 1081). The rails were not turned during welding. The shrinkage stresses acting in the plane of the running surface and determined by the subdivision method, were compressive in head and foot (maximum of 57,000 lb./in.² in the head) and tensile (up to 43,000 lb./in.²) in the web. The compressive shrinkage stresses in the foot of the weld are a favorable factor. (Schulz and Gerold in their report to the third International Rail Conference, 1935, p. 97 showed that residual stresses up to about 21,000 lb./in.² have no effect on the fatigue strength of rails.)

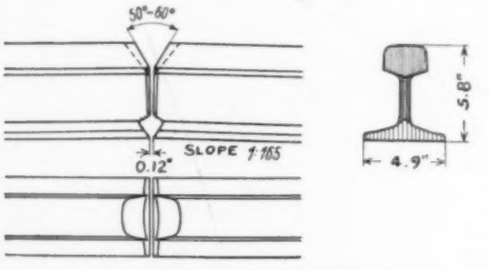

Fig. 1(a)—Method of Welding Plain Rails

Sequence	Diameter of Rod, Inch	Number of Layers	Type of Weld	Remarks
Foot	0.16 and 0.20	2*	Horizontal from above	Two welders at once
Web	0.16	2	Vertical	Two welders at once
Head	0.24	..	Horizontal from above	One welder assisted by preheater; each layer peened

* The root was reverse welded and sometimes peened. Rod GV3 (high-grade low-carbon steel) was used except for the upper ¾ inch of the head which required rod GA3 (high-carbon steel).

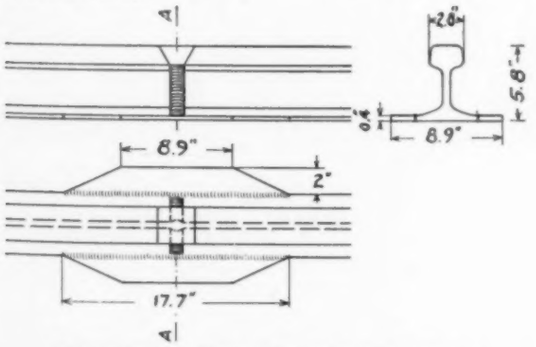

Fig. 1(b)—Butt-Welded Rail with Side Plates

The results show that butt welds may be relied upon for a pulsating bending fatigue strength (0 to max.) of 21,400 to 27,000 lb./in.² which may be compared with 34,100 to 59,800 lb./in.² for the rails without joints.

Butt welds re-enforced with side plates welded to the foot have fatigue strengths of 34,000 to 42,700 lb./in.², which is 70 to 80% of the fatigue strength of rails without joints. All but one of the re-enforced butt welds fractured at the end of the weld joining the side plate to the foot, at which point the fatigue strength was calculated to be only 18,500 lb./in². The decrease is attributed to notch effect which may be removed by shaping the ends of the side plate to lessen the severity of the notch. Tests on butt-welded joints having re-enforcing side plates 32 inches long, 4 inches wide showed that fracture was forced to occur in the butt weld.

Diagonal butt welds (weld vertical but at an angle of 45° to the sides of the rail) have practically no higher fatigue strength than butt welds perpendicular to the sides, because the same defects that lower the fatigue strength are present in both types of joint. Bolted or combination bolted and butt-welded joints have very low fatigue values: 11,000 to 17,000 lb./in². Measurements showed that inappreciable permanent deflections occurred in the butt-welded specimens during fatigue tests up to the fatigue strength.

Although oxyacetylene butt welding reduces the fatigue strength of rails, rust and dents on the foot also lower the fatigue strength. For example, a rusty rail of type K fractured after only 576,100 cycles between 1300 and 43,400 lb./in². A new rail of type K purposely dented on the upper edge of the foot failed after 445,600 cycles between 1300 and 39,300 lb./in.², fracture originating in a dent. Although the reduction in fatigue strength caused by dents is considerable, it is much less than that reported by Schulz and Gerold (Third International Rail Conference, 1935, pp. 100–101) for rails nicked with a cold chisel. Tests are being made to determine the effect of service on the fatigue strength of rails.

Discussing the above results, F. Rosenberg of the Federal Materials Testing Laboratory, Berlin-Dahlem, quoted pulsator tests on flash-welded rails of type K on a span of 3.15 ft. with two loads, each 5 inches from the center. The welded rail, which was prepared on an automatic AEG flash welder, had 91% of the fatigue strength (criterion not stated but presumably 2 million cycles) of

* Abstract of "Über die Dauerbiegefestigkeit von geschweissten Schienen," published in *Autogene Metallbearbeitung*, **31**, No. 15/16 (1938). Translated by G. E. Claussen.

† Technical College, Stuttgart, Germany.

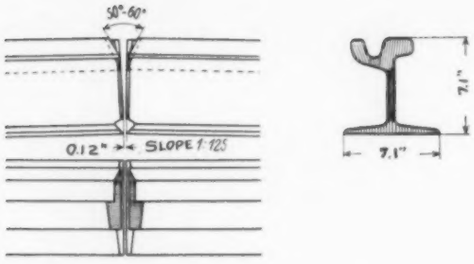

Fig. 2—Method of Welding Grooved Rails

Sequence	Diameter of Rod, Inch	Number of Layers	Type of Weld	Remarks
Foot	0.16 and 0.20	2*	Horizontal from above	Two welders at once
Web	0.16	2	Vertical	Two welders at once
Guard lip	0.20	..	From above	One welder
Head	0.24	..	Horizontal from above	One welder assisted by preheater; each layer peened

* The root was reverse welded and sometimes peened. Rod GV3 was used except for the upper 1/2 inch of the head for which rod GA3 was used.

the unwelded rail. The stress at the fatigue limit for the unwelded rail pulsated between 8200 and 52,300 lb./in.^{2}, the corresponding values for the welded rail being 9700 and 50,000 lb./in^2.

Table 1—Fatigue Tests of Rail K

Type of Specimen	Fatigue Strength, Lb./In.^{2}	Location of Failure in Fractured Specimens
Rail without joint	45,500	Within 3/4 inch of load
Butt weld directly under load	26,300	In weld
Butt weld 2 inches to one side of load	25,600	In weld or near load
Diagonal (45°) butt weld directly under load	24,200	In weld or 1/4 to 2 1/2 inches from load
Butt weld with side plates (St 42) directly under load	37,000	In butt weld or 9 inches from load
Butt weld with side plates (St 60) directly under load	Less than 34,100	7 to 9 inches from load
Bolted joint 0.39 inch from load	10,700	In bolt plates
Combined bolted and butt-welded joint; butt weld directly under load	17,100	In bolt plates

Brinell hardness of rail on running surface = 230–270
Brinell hardness of weld on running surface = 230–300
St 42 = plain carbon steel with minimum tensile strength of 60,000 lb./in.^{2}
St 60 = plain carbon steel with minimum tensile strength of 85,000 lb./in.^{2}

Table 2—Fatigue Tests of Rail GHH

Type of Specimen	Fatigue Strength, Lb./In.^{2}	Location of Failure in Fractured Specimens
Rail without joint; foot in tension	59,800	Within 1/4 inch of load
Butt weld directly under load; foot in tension	26,300	In weld at junction of foot with web
Butt weld directly under load; head in tension	Less than 27,000	At defect in root of weld in head
Butt weld with side plates directly under load; head in tension	42,700	In weld joining side plate to foot of rail
Diagonal (45°) butt weld directly under load; foot in tension	26,300	At defects in weld at junction of foot with web

Brinell hardness of rail = 202–216
Brinell hardness of weld metal = 246–250

Table 3—Fatigue Tests on Duplex Grooved Rail GMW

Type of Specimen	Fatigue Strength, Lb./In.^{2}	Location of Failure in Fractured Specimens
Rail without joint	34,100	Within 2 inches of load
Butt weld directly under load	27,000	In tension zone of weld
Diagonal (45°) butt weld directly under load	25,600	Mainly in defective parts of the weld
Bolted joint, gap between ends of rails = 0.016 to 0.071 inch	14,900	Behind smaller bolt plate

Brinell hardness of rail on running surface = 297–317
Brinell hardness of foot of rail = 143–148
Brinell hardness of weld on running surface = 255–288

Table 4—Fatigue Tests on Special Profile Duplex Rail GMW

Type of Specimen	Fatigue Strength, Lb./In.^{2}	Location of Failure in Fractured Specimens
Rail without joint	48,400	.....
Butt weld directly under load	About 21,400	.....

Brinell hardness of rail = 286–296
Brinell hardness of weld = 302

Table 5—Composition and Dimensions of Rails

		K Flat Bottom Rail	GHH Flat Bottom Rail	GMW Grooved Rail	GMW Special Profile Rail
Carbon content, %	head	0.68	0.51	0.77	...
	foot	0.74	0.51	0.15	...
	web	0.67	0.51	0.15	...
Silicon content, %	head	0.26	0.23	0.25	...
	foot	0.27	0.22	0.24	...
	web	0.28	0.22	0.24	...
Manganese content, %	head	0.90	0.86	0.66	...
	foot	0.92	0.87	0.55	...
	web	0.89	0.87	0.55	...
Chromium content, %	head	0.06	0	0.00	...
	foot	0.06	0	0.03	...
	web	0.06	0	0.03	...
Copper, %		0.12–0.14	0.12–0.13	0.21	...
Nickel, %		0.04	0	0.05	...
Phosphorus, %		0.027	0.029	...	...
Sulfur, %		0.018	0.037	...	...
Height, inch		5.17	5.17	7.1	4.5
Width of head, inch		2.76	2.76	4.54	2.14
Width of foot, inch		5.00	4.95	7.1	3.53
Thickness of web, inch		0.56–0.58	0.55–0.58*	0.49–0.50	0.47–0.50
Weight per yard, lb.		100	100	...	59
Cross-sectional area, sq. in.		9.8	9.7	12.4	5.7
Moment of inertia, in.^{4}		41	43	86	15.6
Yield strength, lb./in.^{2}	head	87,000	71,000	95,000	...
	foot	84,500	65,000	46,800	...
Tensile strength lb./in.^{2}	head	123,000	105,000	162,000	...
	foot	125,000	103,000	66,000	...
Elongation, % in 5 inches	head	12	16	10	...
	foot	15	18	28	...
Reduction of Area, %	head	21	30	9	...
	foot	25	33	57	...

Tensile specimens were 0.39 inch thick, 1.0 inch wide.
* At thinnest section.

COLUMN TESTS OF REINFORCED Channels*

By R. J. ROARK†, C. B. VOLDRICH and E. SOLLID

ABSTRACT

Steel channels of approximately the same length (4½ feet), cross section, and radius of gyration, some of which were fabricated from rolled sections and reinforced by plug or fillet-welded plates, and some of which were unreinforced rolled channels, were tested as columns with free ends. The elastic properties, ultimate load, and characteristics of failure were observed and related to the distortions created by rolling or welding, which were small in most specimens. The resistance of plug and fillet welds to transverse shear also was investigated.

INTRODUCTION

THE purpose of these tests was to compare the properties of solid steel columns with those of columns built up by welding together their component parts.

A steel column which has been subjected to welding may have an appreciable crookedness resulting from the shrinkage of the weld metal when it cools. This shrinkage also sets up local stresses which cause some parts of the column to reach the elastic limit before others, and so produce what is in effect a condition of eccentric loading. Both these conditions are aggravated if the welding is asymmetrical with respect to a principal axis of the column section. Tests have been made on welded columns‡ which had a symmetrical cross section, and on which the welds were symmetrically disposed about the principal axes of the section.

The present tests are an endeavor to show the behavior of non-symmetrical sections, namely channels in which the eccentricities created by welding are confined to the plane perpendicular to the web, and in which the radius of gyration is small, Table 1. The design of the specimens is purely experimental.

The tensile properties of specimens 1½ inches wide cut from the rolled sections and plates in the direction of rolling are given in Table 2. The gage length was 8 inches and a Moore extensometer (0.0001-inch Ames dial) was used. The specimens for the channels were cut from the web. Mill scale was not removed.

Table 2—Properties of Tension Coupons from Column Steel

Column	Coupon	Prop. Limit	Yield Point	Modulus of Elasticity	Ultimate Unit Load
*A*1	*P*-1*a*	21.0	36.0	29.1	60.5
*A*2	*P*-1*b*	21.0	38.3	30.0	60.5
*B*1	*P*-2*a*	18.0	34.1	29.7	61.5
*B*2	*P*-2*b*	27.0	33.3	28.8	59.3
	P-2*c*	27.0	34.8	29.4	61.5
Weighted Ave.		22.7	35.5	29.4	60.7
*C*1	*P*-1*Xa*	21.0	33.9	29.4	56.7
*C*2	*P*-1*Xb*	25.0	37.7	29.9	57.2
	P-4*a*	20.0	33.8	28.9	59.9
	P-4*b*	20.0	34.0	28.6	59.6
Weighted Ave.		21.3	34.8	29.2	58.5
*D*1	*P*-3*a*	25.0	31.8	29.8	58.0
*D*2	*P*-3*b*	17.0	31.3	30.9	57.4
	P-3*c*	20.0	32.4	29.6	58.2
Average		20.7	31.8	30.1	57.9
*E*1	*P*-5*a*	18.0	29.2	29.7	55.5
*E*2	*P*-5*b*	18.0	30.2	29.4	55.3
Average		18.0	29.7	29.6	55.4

Proportional Limit, Yield Point and Ultimate Unit Load are given in thousands of pounds per square inch. Modulus of Elasticity is given in millions of pounds per sq. in.

Table 1—Data on Test Columns

Column	Type of Weld	Length, Inches	Steel Used	Area of Section, Sq. In.	Least I, In.⁴	Least r, In.	$\frac{L}{r}$	$\bar{y}$
	½ In.							
*A*1	Button weld in web	54.00	10-in. Channel 15.3 lb. 10-in. by 9/16-in. Plt.	10.051	4.56	0.67	80.4	0.69
*A*2	Same	53.97	Same	10.011	4.56	0.67	80.4	0.69
	¾ In.							
*B*1	Button weld in web	54.00	Same	10.094	4.56	0.67	80.4	0.69
*B*2	Same	53.97	Same	10.099	4.56	0.67	80.4	0.69
	⅜ In.							
*C*1	Fillet weld on plate	54.03	10-in. Channel 15.3 lb. 9¼-in. by 9/16-in. Plt.	9.771	4.48	0.68	79.4	0.71
*C*2	Same	54.00	Same	9.763	4.48	0.68	79.4	0.71
	⅜ In.							
*D*1	Fillet weld on flanges	53.81	10-in. Channel 35.0 lb. 2-in. steel lugs, ⅜ in. thick	10.178	4.6	0.67	80.4	0.69
*D*2	Same	54.00	Same	10.175	4.6	0.67	80.6	0.69
*E*1	No welds	54.03	10-in. Channel 35.0 lb.	10.121	4.6	0.67	80.6	0.69
*E*2	Same	54.00	Same	10.110	4.6	0.67	80.6	0.69

* Summary of thesis submitted in 1933 by C. B. Voldrich and E. Sollid in the Department of Civil Engineering, University of Wisconsin. Contribution to the Fundamental Research Division, Welding Research Committee.

† Professor of Mechanics, University of Wisconsin.

‡ Slater and Fuller, "Tests of Riveted and Welded Steel Columns," Proc. Am. Soc. C.E., **58**, no. 7, September 1932. AMERICAN WELDING SOCIETY JOURNAL, **12** (2) 20–21 (1932).

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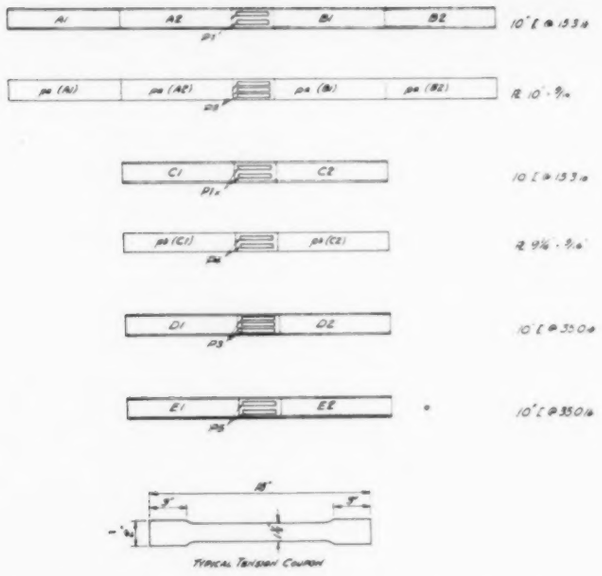


Fig. 1—Location of Tension Coupons in Channel and Plate Stock Used for Columns

FABRICATION

The plates and channels were cut $^1/_4$ inch oversize to permit milling the ends to a final length of 54 inches. Holes for plug welding were punched.

Method of Fabrication of Columns

The channels and plates for the several types of columns were cut from rolled lengths as shown in Fig. 1. The channel stock for columns A, B and C had been rolled some time previous to its being used; the channels for columns D and E had been rolled only a few days before being used.

When the stock had been cut to the desired length (54 inches plus $^1/_4$ inch for machining of the ends), holes were punched in the web of the channels for columns of type A and B, as shown in the column details, Fig. 2.

In welding the plate-and-channel columns, the two parts were clamped together at both ends and at the center. Welds were then placed in the order shown in Fig. 2.

Columns $D1$ and $D2$ were welded at intervals along the toe of the flanges, as shown in Fig. 2. Steel lugs $^3/_8$ inch thick and 2 inches long were clamped to the inside of the flanges, and were then welded to the channel. The lugs served only as a base for the weld bead, and were not intended to build up the channel.

Welding was stopped when half of the welds had been made on any one column, in order that excessive heating of the sections might be prevented.

The approximate amperage and voltage used in welding each column were recorded, as well as the time required to make each plug or fillet-weld. These data are given in Table 3.

A standard commercial brand of coated welding rod was used for all the welds. After the columns had been welded, the ends were milled flat and as parallel to each other as possible.

Sections were taken at random through welds on the different types of columns after these had been tested.

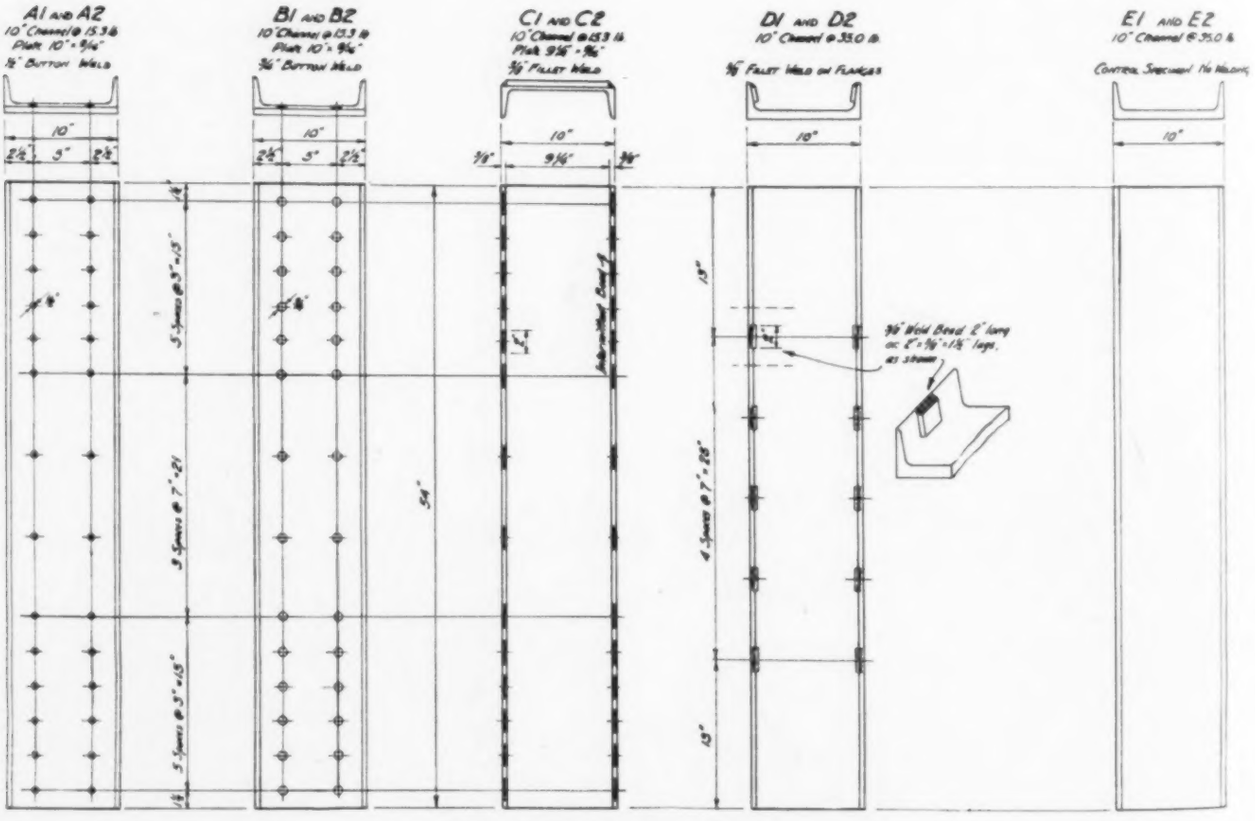
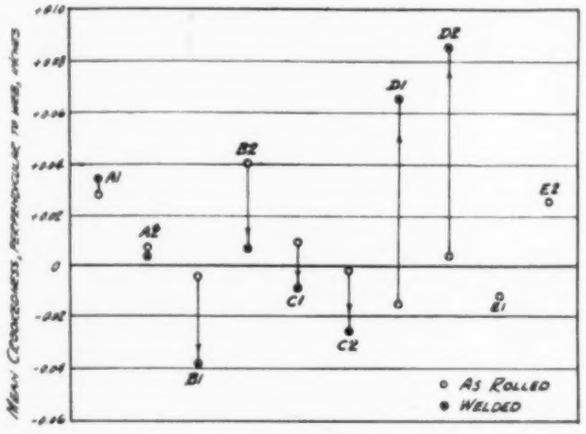


Fig. 2—Details of Columns Tested

Table 3—Welding Data

Column	Type of Weld	Approximate Volume of Weld, Cu. In.	Average Welding Time per Weld, Seconds	Diameter of Welding Rod, Inch	Amperes	Volts	Index of Welding Time. (No. of Seconds Required to Deposit 0.01 Cu. In. of Weld)
*A*1	1/2-in. Plug	0.047	17	5/32	180	44	3.62
*A*2	1/2-in. Plug	0.047	17	5/32	180	44	3.62
*B*1	3/4-in. Plug	0.106	25	5/16	200	30	2.36
*B*2	3/4-in. Plug	0.106	25	5/16	200	30	2.36
*C*1	3/8-in. Fillet	0.140	24	1/4	230	35	1.71
*C*2	3/8-in. Fillet	0.140	26	1/4	220	35	1.85
*D*1	3/8-in. Fillet	0.140	25	1/4	180	40	1.79
*D*2	3/8-in. Fillet	0.140	25	1/4	180	40	1.79

Columns *E*1 and *E*2, no welding.



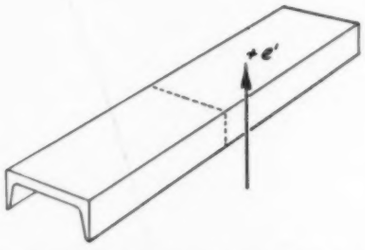


Fig. 3—Change in Mean Crookedness at Center of Columns Due to Welding

The sections were surface-ground, polished with fine emery, and etched with a 10% solution of nitric acid to bring out the welds and highly heated adjacent zones. It was found that good penetration of the weld-metal into the channel and the plate had been obtained, both in the plug welds and in the fillet welds. In the fillet welds, a very slight void or unwelded area was found at the root of the fillet, but the resulting voids were not large enough to affect the strength of the welds.

CROOKEDNESS

Crookedness of the columns before and after welding was measured in a direction perpendicular to the plane of the web.

By means of three Ames dials attached to a stiff steel bar, the displacement of three sections of the column with respect to the end sections was obtained. Readings were taken on the back of the channel web before welding, and on the back of the plate (now the back of the web) after welding, on lines at the edges of the column and on the center-line of the web. It was assumed that any crookedness or curvature of the plate would not affect the final curvature of the column after the plate had been welded to the channel, since the stiffness in longitudinal bending or torsion of the plate was very small.

Since the readings on the Ames dials were referred to a known level surface as a standard, the difference in the readings before and after welding was equal to the change in crookedness of the column perpendicular to the web, resulting from the welding operation.

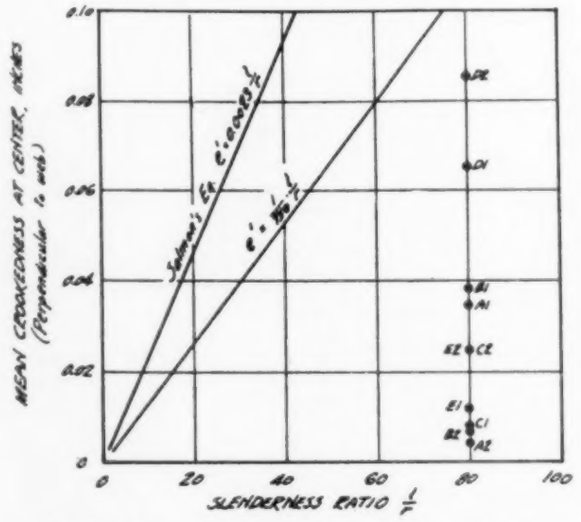


Fig. 4(*a*)—Relation of Crookedness to Slenderness Ratio

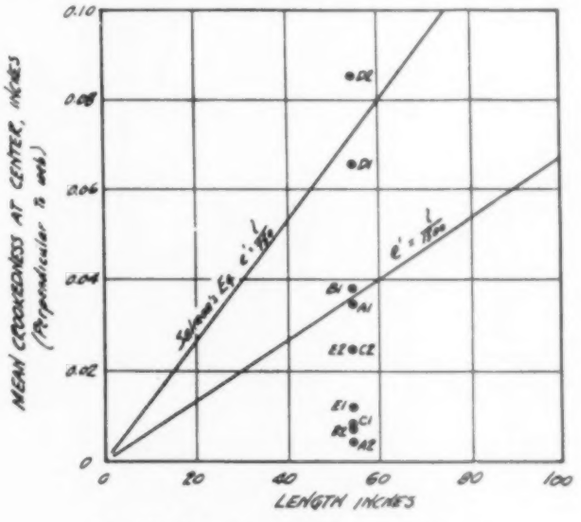


Fig. 4(*b*)—Relation of Crookedness to Length

The effective mean crookedness of the columns was taken as the average of the readings on the center section of the columns at the edges. The crookedness at the center-line of the web was neglected. Figure 3 shows the change in the mean crookedness of the columns due to welding. Figure 4(*a*) shows the relation between the mean crookedness and the slenderness ratio of the columns, and Fig. 4(*b*) shows the relation between the mean crookedness of the columns and their length.

In the second progress report of the Special Committee on Steel Column Research (American Society of Civil Engineers)* a comparison is made between the mean crookedness, slenderness ratio and length of solid and riveted columns. The crookedness of these columns was due to rolling (and perhaps in part to riveting of the built-up sections), and was in some cases very high. The crookedness of the welded columns is comparable to the crookedness of the rolled columns described in the report of the Special Committee, and, with the exception of columns $D1$ and $D2$, never exceeds that given by the Special Committee as the probable crookedness ($e' = 0.00067L$), for any given length.

Welding had a slight effect on the crookedness of columns $A1$ and $A2$. The maximum change in crookedness was 0.02 in. in a direction causing concavity on the inside of the column web.

Columns $B1$ and $B2$, with a greater volume of deposited weld-metal, had a distinct change in crookedness due to welding. Column $B2$ had an initial curvature convex on the outside of the web, but welding caused this curvature to decrease and, on the center line of the web, to become concave on the outside of the web. Column $B1$ was fairly straight before welding; after welding there was a maximum crookedness of 0.04 in. to 0.05 in. in the direction of the inside of the web. The change in crookedness of both $B1$ and $B2$ was a displacement of the central portion in the direction of the inside of the web, this change being caused by or accompanied by the shortening of the plate in the longitudinal direction.

Columns $C1$ and $C2$ also had a final crookedness convex on the inside of the web, due to a shortening of the weld beads and the plate, but the average change in crookedness was not so great as in columns $B1$ and $B2$.

Columns $D1$ and $D2$ were subjected to welding on the toes of the flanges, this region being most remote from the neutral axis of the column section. The contraction of the weld beads caused a very large curvature in the direction of the outside of the web, the maximum departure from a straight line being about 0.08 in. at the mid-length of the columns.

The crookedness of a column after welding probably depends as much on temperature differences at various zones on the section during welding, as on shrinkage of the weld-metal. This is especially true for the plate-channel columns.

It is difficult to analyze the effects of temperature and of weld shrinkage separately. The crookedness is caused partly by local welding strains, but this crookedness may in turn set up new strains, which combine with the welding strains to give the measured deformations. The relation between temperature differences and weld shrinkage is not known, and hence the proportionate effect of each on the crookedness cannot be determined.

Figure 5 shows the lateral alignment of the columns

* Transactions of the American Society of Civil Engineers, **95**, 1931. Pages 1230 to 1232 include a discussion of the crookedness of columns.

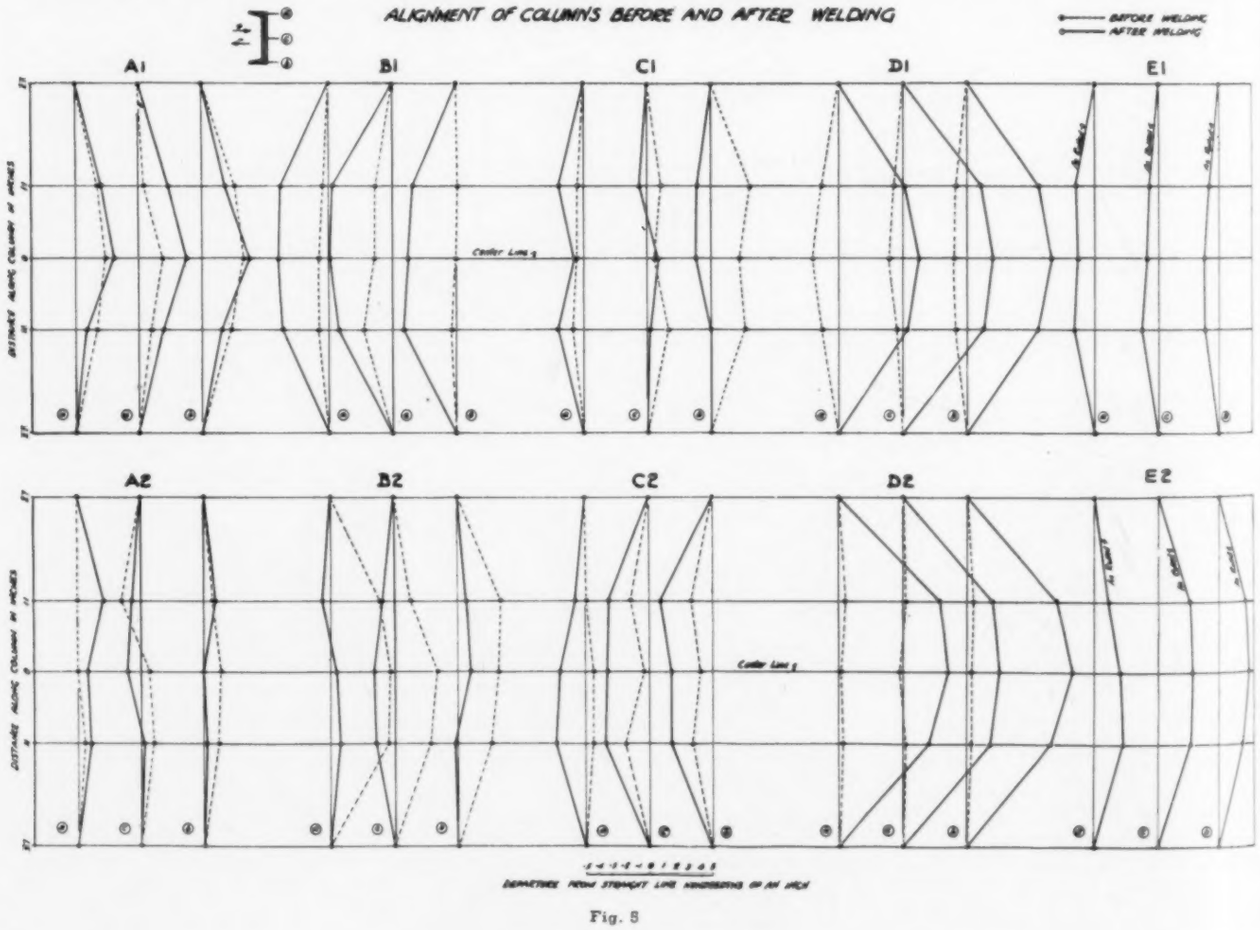


Fig. 5

before and after welding. Where the amount of weld-metal was large, the change in crookedness was large (Compare $A1$ and $A2$ with $B1$ and $B2$). When the distance between the plane of the welds and the neutral plane of the column was considerable, as in columns $D1$ and $D2$, the change in crookedness was very large.

To summarize, the crookedness of the columns due to welding depends to an unknown extent on the following factors:

1. Character and magnitude of welding strains.
2. Temperature differences in the column section.
3. Location of the plane of welds with respect to the neutral plane of the column (that is, the asymmetry of weld distribution with respect to the neutral plane).

LOCAL STRAINS

It was impossible to determine shrinkage stresses because the columns could not be subdivided by sawing before column testing. An analysis of the shrinkage stresses in plug welded specimens of different shape has been made.[1] Nevertheless, an Olsen extensometer (2 inches) was used to measure strains created by welding the columns. Strains were measured in the direction of the column axis at zone between and across welds, on lines along the welds. The readings were made at corresponding points on both sides of the web of the column. Strain measurements were also made at the edges of the plate and at the toe of the channel flanges, at zones near the mid-length of the column, and at zones where the welds were closely spaced.

The results showed that in the plug welded columns $A1$ and $A2$ the highest strains occurred at the inside of the web, in the zone where the welds were closely spaced. There was an elongation between the welds, and a shortening across the welds. The strains on the outside of the web along the line of the welds were low and negative indicating a shortening of the plate in the longitudinal direction. At the gage lines on the edges of the plate and at the toe of the channel flanges the strains were low, and with one exception, always a shortening.

In columns $B1$ and $B2$, the volume of deposited weld-metal was about twice that deposited in the welds of columns $A1$ and $A2$, and the diameter of the welds was about 50% greater. The character of the strains on columns $B1$ and $B2$ is the same as in corresponding points on $A1$ and $A2$, but the strains in $B1$ and $B2$ are from 20% to 30% higher in most instances. The effect of volume of deposited weld-metal is evident from this comparison of the strains in types A and B; its effect on the crookedness of the columns is also distinct, and will be shown in the discussion on crookedness.

Columns $C1$ and $C2$, with stitch-welds along the edges of the plate at the heels of the channel, were strained similarly to the plug welded types A and B. The strain is a lengthening between weld beads, and a shortening across the beads. At any given zone at the welded edge of the column, the strain in the plate is usually much larger than the strain in the heel of the channel. The strains in the toe of the channel flanges are low.

The welding strains in columns $D1$ and $D2$ were highest at the toe of the channel flanges, across the weld beads; at these points the shrinkage of the weld-metal caused a marked contraction of the adjacent area. Between welds on the flange toes there was a relatively slight lengthening. At the mid-length of the columns at points on the heels of the channels, the strains were small. At the center-line of the web, near mid-length, the strains were also very small.

[1] Roark, R. J., *ASCE Proc.*, **59** (1), January 1933.

A rigid analysis of the effects of temperature difference in the plate and the channel, and of the order of welding, is believed to be impracticable and will not be attempted. In columns $D1$ and $D2$ the strains and crookedness due to welding arise mainly from shrinkage of the weld-metal. In column types A, B and C, difference in temperature of plate and channel during welding, and the order of welding, will affect the magnitude and distribution of strain. Since the plate, after the first welds had been made at each end, was fixed to the channel, no movement of the plate relative to the channel was possible when additional welding was done. This condition resulted in strains which would not have occurred if the plate had been free to lengthen or shorten during welding (as would have been the case if the plate had been welded progressively from the center toward the ends).

The tables of welding strains in Fig. 6 and Table 4 show that between welds there was an elongation of the metal. It is reasonable to assume that this elongation is accompanied by an actual residual tensile stress, the magnitude of which, however, cannot be determined from the strain readings (due to the effect of plastic flow and possible overstressing beyond the yield point). This tensile stress, if present, may closely approach the yield point of the material.

Table 4—Approximate Maximum Crookedness and Plastic Strain Values, Welded Columns

Mark	Kind	Approx. Max. Plastic Strain Inches/Inch
$A1$	1/2-in. Plug	0.0050
$A2$	1/2-in. Plug	0.0046
$B1$	3/4-in. Plug	0.0104
		0.0065
		0.0068
$B2$	3/4-in. Plug	0.0058
		0.0060
$C1$	Fillet (with plate)	0.0023
		0.0044
$C2$	Fillet (with plate)	0.0040
		0.0041
		0.0047
$D1$	Flange (lugs)	0.0040
$D2$	Flange (lugs)	0.0053

$E1$ and $E2$, basic control specimens, no welding, no strain readings.

Note on strains: maximum strains usually occurred between welds.

Note similarity of strain readings on identical gages in specimens ($A1 + A2$), ($B1 + B2$) and ($C1$ and $C2$).

COLUMN TESTS

Test Conditions

The columns were tested with their ends free to rotate about the axis of least radius of gyration. The ends of the columns were centered on roller-bearing blocks so that the minor centroidal axis of the end sections coincided with the axis of rotation of the bearings. The line of action of the load passed through the centroids of the end sections; hence the columns were tested with an initial eccentricity equal to the crookedness of the columns.

Strain measurements were made with a 2-inch Olsen strain gage at zones between and across welded sections, and at the center of the column. The location of the zones at which strain measurements were made is shown in Fig. 7. The stress-strain diagrams were plotted from the averages of readings on these points around the section. Two wire-wound dials attached to the column in

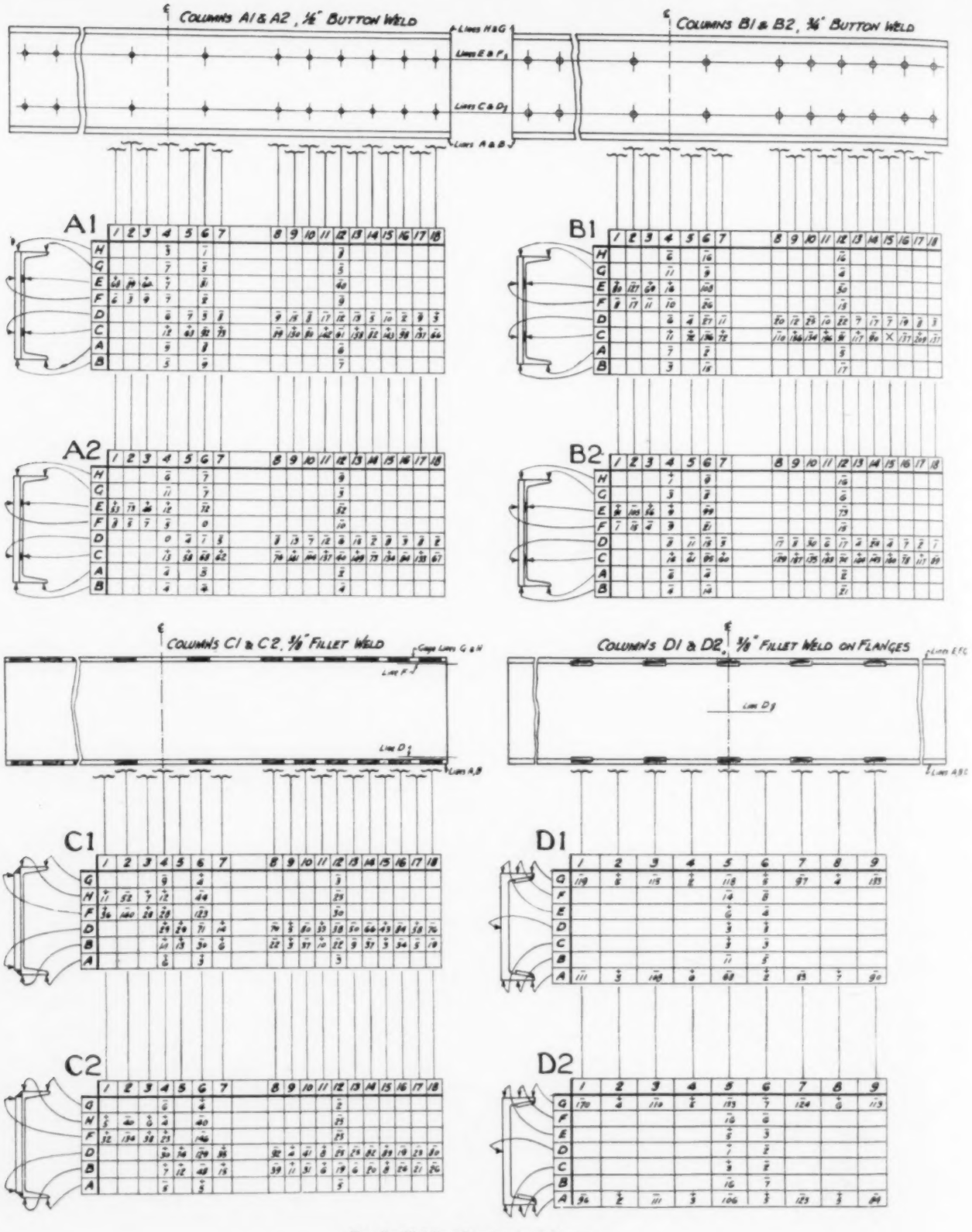


Fig. 6—Welding Strains in Columns

Strain given in terms of apparent stress, in kips. (= unit strain × 30,000,000)
Minus sign indicates shortening of the gage length after welding, or a compressive stress
Plus sign indicates lengthening of the gage length after welding, or a tensile stress

the plane of the minor centroidal axis measured the strain over an $18^1/_2$ inch length spanning a representative portion of the column; that is, the $18^1/_2$ inch length included part of the heavily welded region, and part of the region in which welds were widely spaced. The lateral deflection was measured with an Ames dial reading to

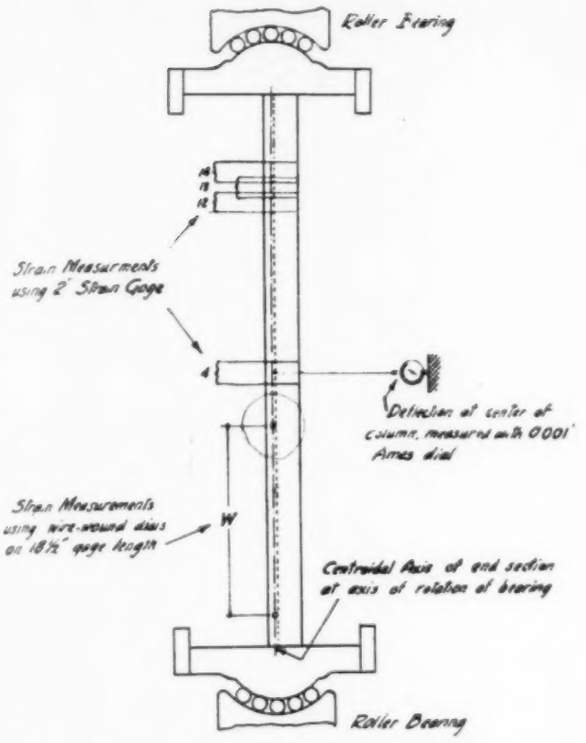

Roller Bearing
Strain Measurements using 2" Strain Gage
Deflection of center of column, measured with .0001" Ames dial
Strain Measurements using wire-wound dials on 18½" gage length
W
Centroidal Axis of end section at axis of rotation of bearing
Roller Bearing

Fig. 7—Typical Column Test Set-Up Showing Location of Load-Strain Measurements

0.0001 inch, connected to the inside of the column web at the center.

A thin coat of white Portland cement was applied to each column several hours before it was tested. The purpose of this cement wash was to make visible any flaking of mill-scale on the column resulting from local yielding under load.

The machine used for the column tests was of the hydraulic type, with a capacity of 600,000 lb. The load was measured on the weighing beam of an auxiliary hydraulic testing machine, the piston of which was directly connected to the piston of the 600,000-lb. machine by means of an oil line. The measured load was equal to the axial load on the column, neglecting any error which might have been introduced by the friction of the piston or the viscosity of the oil.

The load was kept constant while strain measurements were being taken. As a check on the constancy of the load the readings on the wire-wound dials and on the deflectometer were taken at the beginning and the end of each series of readings.

Elastic Properties

The proportional limit was taken as the point on the stress-strain diagram at which a distinct break occurred in the curve.

The modulus of elasticity was taken as the slope of the line passing through the points on the stress-strain diagram up to the proportional limit. The modulus of elasticity, as obtained from strain measurements at local zones, is not necessarily the actual modulus of elasticity of the material, since the value as obtained from strain readings may be affected by non-uniform stress distribution.

Table 5 gives the proportional limit and the modulus of elasticity, as obtained from the stress-strain diagrams, for the five zones on each column. In addition to these data, the ultimate load on each column is given, and the physical properties of the steel making up each column, as obtained from the coupon tests are listed.

Table 5—Physical Properties of Columns from Tests

Column	Zone	Prop. Limit	Yield Point	Modulus of Elasticity	Ultimate Unit Load
*A*1	4	16.0		27.4	
	12	16.0		29.4	
	13	16.0		27.6	
	14	16.0		27.6	
	W	22.0		32.5	
					24.0
*A*2	4	18.0		27.4	
	12	18.0		28.6	
	13	18.0		27.8	
	14	18.0		28.6	
	W	19.0		26.7	
					23.5
*B*1	4	*		26.1	
	12	10.0		28.2	
	13	12.0		27.3	
	14	22.0		28.2	
	W	14.0		30.0	
					25.9
*B*2	4	20.0		25.4	
	12	14.0		25.1	
	13	14.0		27.4	
	14	18.0		27.8	
	W	20.0		31.7	
					29.0
Average of coupon tests for columns *A*1, *A*2, *B*1 & *B*2		22.7	35.5	29.4	60.7
*C*1	4	16.0		30.3	
	12	16.0		30.3	
	13	16.0		29.2	
	14	16.0		30.8	
	W	16.0		30.8	
					26.3
*C*2	4	16.0		27.4	
	12	16.0		28.0	
	13	16.0		27.8	
	14	16.0		28.6	
	W	16.0		31.7	
					26.3
Average of coupon tests for columns *C*1 and *C*2		21.3	34.8	29.2	58.5
*D*1	5	14.0		29.6	
	7	14.0		30.2	
	8	14.0		30.2	
	9	14.0		28.2	
	W	14.0		29.4	
					22.0
*D*2	5	16.0		26.0	
	7	14.0		25.5	
	8	16.0		26.0	
	9	14.0		26.0	
	W	18.0		31.8	
					20.1
Average of coupon tests for columns *D*1 and *D*2		20.7	31.8	30.1	57.9
*E*1	4	19.0		28.2	
	12	20.0		27.0	
	13	20.0		27.2	
	14	20.0		26.7	
	W	19.0		29.9	
					24.1
*E*2	4	15.0		28.2	
	12	17.0		28.2	
	13	17.0		27.3	
	14	*		26.0	
	W	17.0		30.1	
					25.0
Average of coupon tests for columns *E*1 and *E*2		18.0	29.7	29.6	55.4

Proportional Limit, Yield Point and Ultimate Unit Load are given in thousands of pounds per square inch.

Modulus of Elasticity is given in millions of pounds per square inch.

* Asterisk denotes that the proportional limit was at or near the ultimate load (no break in curve).

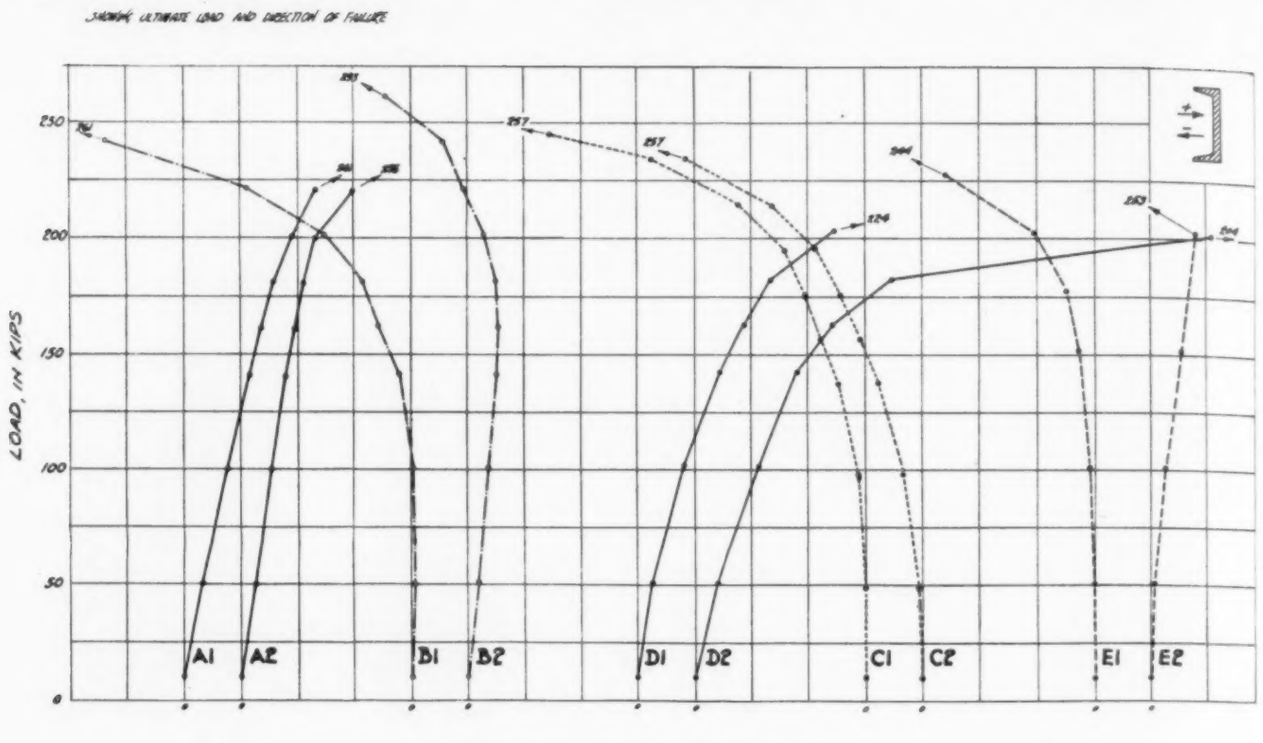


Fig. 8—Lateral Deflection of Columns

Description of Failure

In all of the columns, failure was caused by a deflection of the column in a plane perpendicular to the plane of the web. The final deflection occurred suddenly as the ultimate load was reached, although impending failure could be detected in most cases by the increasing rate of deflection as indicated on the Ames dial. Figure 8 shows the load-deflection curves for the columns.

In no case was there a failure in the welds, or a buckling of the plate or channel web between welds, during the test.

Strain Lines

The coating of neat cement which was applied to the columns before they were tested afforded the opportunity of detecting local yielding in the member only when a coating of mill scale was present. The channels used in fabricating the columns had little or no mill scale, and therefore no visible strain lines developed on the channels until very high yielding had taken place at or near failure. At this point the cement wash flaked.

The plates used in fabricating the columns of types *A*, *B* and *C* had a good coat of mill scale; strain lines developed on the plates at relatively low loads.

It is probable that the channels were overstressed in local areas before the elastic limit of the column as a whole had been reached, but no visible proof of this could be observed, because there was no mill scale on the channels. In the interpretation of the following data on strain line development in the columns, this fact should be kept in mind.

In columns of types *A* and *B* the first visible strain lines were horizontal and originated at the edge of the plate. The lines extended on the face of the plate toward the adjacent plug weld, Fig. 9. At higher loads a continuation of the strain lines appeared on the side of the plate at 45° to the plane of the plate. The first lines appeared 10 to 15 inches from the ends of the columns. No lines appeared over the welds.

In the columns of type *C* strain lines appeared on the face of the plate about 1 foot from the ends of the column and extended from the edge of the plate horizontally toward the middle. The origins of the lines were areas at which flaking of the mill scale occurred during cooling after welding. At 15,000 lb./in.² lines were observed on column *C*1 at the edges of the plate adjacent to all weld beads except those at the extreme ends of the column. As the load was increased, the lines progressed horizon-

Table 6—Comparison Between Proportional Limit and Strain Lines

Column	Unit Load, Kips per Sq. In., at Which the First Strain Lines Appeared	Proportional Limit, Kips per Sq. In., from the Stress-Strain Diagrams				
		Zone				
		4	12	13	14	W
*A*1	19	16	16	16	16	22
*A*2	18	18	18	18	18	19
*B*1	14	..	10	12	22	14
*B*2	14	20	14	14	18	20
*C*1	14	16	16	16	16	16
*C*2	14	16	16	16	16	16
*D*1	No strain lines until failure					
*D*2	" " " " "					
*E*1	" " " " "					
*E*2	" " " " "					

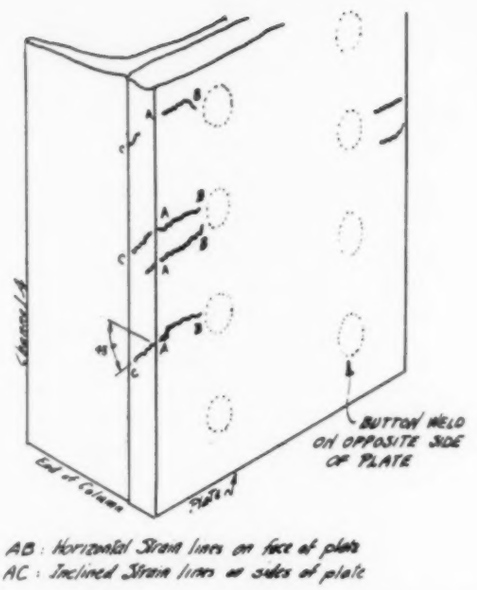

BUTTON WELD
ON OPPOSITE SIDE
OF PLATE
AB : Horizontal Strain lines on face of plate
AC : Inclined Strain lines on sides of plate

Fig. 9—Typical Development of Strain Lines on Button-Welded Columns of Type *A* and *B*. Lines Begin at Point *A*, Grow Inward to *B* on Face of Plate, and Downward to *C* on the Side of the Plate

tally toward the middle of the plate. Strain lines inclined at 45° to the vertical appeared on the face of the plate at a load of 20,000 lb. per sq. in. These lines began at the edges of the plate adjacent to weld beads, or at the inside termination of horizontal strain lines, and crossed the face of the plate at 45°, to welds (or the termination of horizontal strain lines) on the other edge.

A comparison of the unit load at which strain lines first appeared on the columns and the proportional limit at different zones in the columns is given in Table 6. There seems to be some relation between the two; it is probable that the initial stresses in the columns influenced both.

Eccentricity and Extreme Fiber Stress Due to Bending

Table 7 is a comparison of the initial crookedness e', total eccentricity e and the approximate eccentricity due to internal effects, e_i; the bending stress on the extreme fibers is also given, as calculated from the formula given below, and as calculated from strain measurements on the extreme fibers.

The total eccentricity e with respect to the axis of minimum radius of gyration, for a given load, was calculated from the formula

$$e = \frac{Wr^2}{Xy}$$

in which e, r and y represent, respectively, the eccentricity, radius of gyration and the distance to the fibers on which strain measurements were made. The values of r and y are given for each column in Table 1. W equals the difference in the sums of the deformations on the two sets of gages, J and N, and L and P, at the center section of the column, Fig. 10. X equals the sum of the deformations on the four gages J, N, L and P, at the center section.

The eccentricity due to internal effects was found by substracting the center deflection from the total eccentricity e. $e_i = e - D$

The bending stress on the extreme fibers was calculated

(1) from the formula

$$\text{Bending Stress} = \frac{PW}{AX}$$

Table 7—Comparison of Initial Crookedness with Total Eccentricity, Deflection and Eccentricity Due to Internal Effects. Bending Stresses at Extreme Fibers

Column	Mean Crookedness at Center, e' in Inches	Unit Load P/A Lb per Sq. In.	Total Eccentricity e, Calculated from Strain Measurements, Inch	Deflection at Center Inches	Eccentricity Due to Internal Effects e_i, in Inches	Bending Stress at Toe of Flange, in Lb. per Sq. In. from Formula	Bending Stress at Toe of Flange, in Lb. per Sq. In. from Strain Measurements on Extreme Fibers
*A*1	+0.034	14,000	+0.115	+0.023	+0.090	− 8500	−6800
*A*2	+0.004	14,000	+0.038	+0.016	+0.022	− 2900	−3400
*B*1	−0.038	14,000	−0.025	−0.004	−0.021	+1900	+3200
*B*2	+0.007	14,000	+0.046	+0.011	+0.035	− 3500	−1400
*C*1	−0.008	14,000	+0.019	−0.009	+0.028	+ 1500	+2000
*C*2	−0.025	14,000	−0.022	−0.015	−0.007	+ 1700	+3800
*D*1	+0.065	14,000	+0.133	+0.029	+0.104	−10200	−4800
*D*2	+0.085	14,000	+0.094	+0.037	+0.057	− 7100	−7000
*E*1	−0.012	14,000	−0.005	−0.005	0	+ 400	+ 300
*E*2	+0.025	15,000	+0.060	+0.011	+0.049	− 4900	−2000

Eccentricities of Welded Steel Columns
Eccentricity from the Secant Formula

P/A 14,000	P/A Ult. Load
0.177	0.035
0.177	0.039
0.636	0.088
0.636	0.043
0.618	0.077
0.618	0.077
0.148	0.036
0.148	0.052
0.256	0.061
0.256	0.049

Note on crookedness: Negative sign denotes concavity of specimen, plate side up.

This formula gives the stress at y distance from the neutral axis. Assuming the intensity of stress to vary as the distance from the neutral axis, the bending stress on the extreme fibers (toe of flange) is easily found.

(2) from strain measurements taken at the center of the column on the toes of the flanges (these gages are not shown in Fig. 10(*d*).

$$\text{Bending stress} = Ed - P/A$$

where E = 29,000,000 lb. per sq. in.
d = deformation on extreme fibers at the load P/A.

The actual ultimate loads for columns $B1$ and $B2$ were about 5% and 17% higher, respectively, than the calculated ultimate load.

The actual ultimate loads for columns $D1$ and $D2$ were about 11% and 18% lower, respectively, than the calculated ultimate load.

Calculation of Theoretical Ultimate Load

Table 8 gives the comparison between the actual ultimate unit load and the ultimate unit load calculated from the formula

$$P/A = Sy - C(L/r)^2$$

where Sy is the yield point of the steel, lb. per sq. in., as obtained from the coupon tests
C is a constant depending on end conditions, eccentricity, etc.
L/r is the slenderness ratio

The factor Sy used in the formula was the average of the yield point values for all columns. The factor C was first computed for each column by substituting in the formula the Sy, L/r, and actual P/A for that column and solving for C. The average value for C for all columns was then found, and this value, along with the average Sy, was used in computing the theoretical P/A.

Table 8 shows that in columns $A1$ and $A2$, and $E1$ and $E2$, the calculated and actual ultimate loads are in good agreement.

The actual ultimate loads for columns $C1$ and $C2$ were about 5% higher than the calculated ultimate loads.

Table 8—Comparison of Actual Ultimate Unit Load on Columns with the Ultimate Unit Load Calculated from the Formula

$$P/A = Sy - C(L/r)^2$$

Column	Yield Point from Coupon Tests Sy	Actual P/A from Column Tests	L/r	C from the Above Formula	Calculated P/A Using Average Values of Sy and C
$A1$	35.5	24.0	80.4	1.78	24.7
$A2$	35.5	23.5	80.4	1.86	24.7
$B1$	35.5	25.9	80.4	1.49	24.7
$B2$	35.5	29.0	80.4	1.01	24.7
$C1$	34.8	26.3	79.4	1.35	24.9
$C2$	34.8	26.3	79.4	1.35	24.9
$D1$	31.8	22.0	80.4	1.52	24.7
$D2$	31.8	20.1	80.6	1.80	24.6
$E1$	29.7	24.1	80.6	0.86	24.6
$E2$	29.7	25.0	80.6	0.72	24.6
	33.5 (average)			1.37 (average)	

Yield Point and Ultimate Unit Load are given in thousands of pounds per square inch.

The Influence of Welding on the Behavior of the Columns

The effects of welding on the mechanical properties of the columns tested may be divided into two parts, (1) the effect of local welding strains on the properties of the adjacent area, and (2) the effect of crookedness due to welding on the column as a whole.

Initial stresses in a column may cause local yielding in some zones at relatively small axial loads. The stress-strain diagrams showed that the proportional limit at some zones was very low; this may be the result of local overstressing due to welding, but the inherent properties of the material in those zones may also have been such as to give the low proportional limit.

These tests would seem to indicate, however, that there is no definite relation between the initial stresses and the ultimate strength of the columns. The maximum loads carried by some of the welded columns were in fact greater than the maximum loads carried by the rolled sections $E1$ and $E2$. In making this comparison between different columns it has been assumed that the properties of the steel entering all of the columns were the same. The coupon tests showed that the yield point and the modulus of elasticity were fairly uniform for all sections of the columns, although the proportional limit showed a greater variation.

Although the effect of initial stresses due to welding on the ultimate strength of columns may be negligible, the influence of crookedness due to welding on the action of the columns under axial loading must be given some consideration.

In so far as the initial stresses cause crookedness, they affect the column strength; hence, it is not entirely correct to say that the welding stresses have no influence on the behavior of the columns. But if we consider crookedness as a distinct result of welding, due only partially to welding stresses, then we may discuss the effect of crookedness, as such, on column strength.

It will be seen that the crookedness of two of the columns, $B2$ and $C1$, was greater before welding than after welding. Here the effects of welding, as far as they

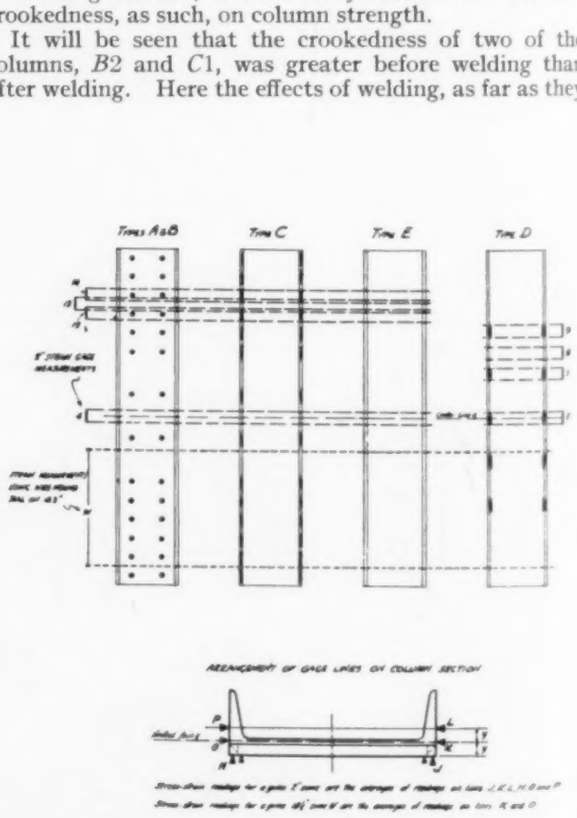


Fig. 10—Location of Strain Measurements

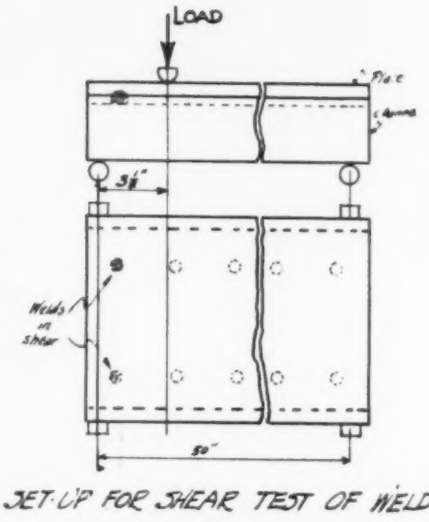


Fig. 11—Method of Loading End of Column Section to Produce Shearing Stress in End Welds

are confined to crookedness, were beneficial, since these two columns carried relatively high maximum loads.

Table 9—Comparison of Initial Crookedness, Direction of Failure and Ultimate Strength of the Columns

Column	Initial Mean Crookedness at Center, in Inches	Direction of Final Deflection (Sign)	Direction of Final Deflection (Toward)	Ultimate Unit Load in Kips per Sq. In.
*A*1	+0.034	+	Web	24.0
*A*2	+0.004	+	Web	23.5
*B*1	−0.038	−	Flange	25.9
*B*2	+0.007	−	Flange	29.0
*C*1	−0.008	−	Flange	26.3
*C*2	−0.025	−	Flange	26.3
*D*1	+0.065	+	Web	22.0
*D*2	+0.085	+	Web	20.0
*E*1	−0.012	−	Flange	24.1
*E*2	+0.025	−	Flange	25.0

Where the crookedness due to welding was very large, as in columns *D*1 and *D*2, the maximum load was low. However, column *A*2 had almost no initial crookedness, but it failed at a load only 10% higher than column *D*1.

Table 9 lists the initial mean crookedness, direction of failure, and the ultimate unit load for each column. An interesting fact brought out by a comparison of the data in this table is that those columns which failed in the direction of the web (*A*1, *A*2, *D*1 and *D*2) had the lowest ultimate loads. The other columns, failing in the direction of the flanges, carried higher loads.

Columns *B*2 and *E*2 failed in a direction opposite to the direction of initial mean crookedness. Both of these columns had a higher ultimate strength than their respective counterparts, *B*1 and *E*1, which failed in the direction of the initial crookedness.

Columns *C*1 and *C*2 had initial crookedness of 0.008 inch and 0.025 inch, respectively, in the same direction, but both columns carried the same maximum load.

It is certain that a column with a very large initial crookedness will fail under a smaller load than a column with a relatively small initial crookedness. It is impossible, however, to furnish a criterion for maximum allowable crookedness from the results of tests on ten columns. The behavior of columns *B*2 and *E*2, whose deflection reversed in direction during loading, and the apparent influence of the direction of failure on ultimate strength, seem to indicate that the load-carrying capacity of the columns was influenced by some unbalanced condition on the column section. It may be that the physical properties of the material in the flanges were sufficiently different than the properties of the web material to cause an unequal yielding in these zones (independent of initial stresses). This action if large enough would influence the direction of deflection, and may also explain the relation which seems to exist between the direction of failure (and hence the character of the bending stresses in the flanges and web, respectively) and the ultimate strength.

The only safe conclusions which can be reached regarding the effect of welding on crookedness and the influence of this crookedness on column strength, on the basis of these tests, are:

1. If the welds are asymmetrically disposed about the column section, the crookedness of the column will be changed; this change is probably mainly due to shrinkage of the weld-metal and to local heating and cooling of the base metal.
2. Welding, whether it be symmetrical or not, may change the longitudinal alignment of the column, if there is a sufficient difference in temperature in different zones of the column section during welding. This is especially true where the column is composed of several parts which are welded together.
3. Crookedness due to welding, combined with other conditions, such as local yielding (not necessarily due to welding stresses) and the inherent eccentricity of the column section, will influence the action of the column under axial loading, and may decrease the maximum load that the column can carry.
4. The crookedness of the welded columns, while greater than that of the two rolled columns here tested (*E*1 and *E*2), is of the same order of magnitude as the crookedness of rolled and riveted columns. A study of the data on the crookedness of rolled and riveted columns[2] shows that even columns *D*1 and *D*2, with welds so placed as cause maximum possible crookedness, were no more crooked than some rolled sections. (The comparison was made on the basis of the relation of crookedness to length of the columns.)

TRANSVERSE SHEAR RESISTANCE OF THE COLUMNS

An attempt was made to determine the approximate resistance to transverse shear of the plug-welded columns *A*1 and *B*1, and the fillet-welded column *C*1, by subjecting the columns to a high transverse shear at the end section including one welded zone (two welds). The horizontal shear due to the loading as shown in Fig. 11 is transmitted to the plate from the channel through the two welds. Yielding or failure of the welds due to this horizontal shear was determined by the first appearance of an offset between plate and channel at the milled end of the column.

The loads were recorded at which first offset and a distinct offset could be determined. The approximate shearing stress on the welds at the recorded loads was calculated as follows:

Total shear at welded section (equal to the total horizontal thrust on the plate at the section)

$$V = Ma'y'/I$$

where M = moment due to the applied load, in.-lb.
a' = area of plate, sq. in.
y' = distance in inches from centroid of plate to centroid of column section

[2] Second Progress Report of the Special Committee on Steel Column Research, Transactions of the American Society of Civil Engineers, **95**, 1932, pp. 1230 to 1233, and Figs. 35 and 37.

I = moment of inertia, in.^{4}, of the column section.

The unit shearing stress on the welds is equal to the total shear V divided by the area of the welds at the section (circular area of plug-welds, or area at the throat of the fillet-welds).

$$S_s = V/a_w$$

where S_s = unit shearing stress on the two welds
V = total shear at the section
a_w = area of two welds.

Table 10—Transverse Shear Resistance of Plug Welded Channels

Column	Load Recorded at	Area of Two Welds, Sq. In.	Calculated Unit Shearing Stress, Lb./Sq. In.
*A*1	First offset	0.40	61,000
	Distinct offset		88,000
	Snap in weld		157,000
*B*1	First offset	0.88	54,000
	Distinct offset		70,000
*C*1	First offset	1.00	46,000
	Distinct offset		58,000

The results of these tests are given in Table 10.

The flanges of the columns began to fail in bearing at loads which caused the first offset. The results are therefore affected by the friction of the flanges and the friction of the plate on the channel; that is, this friction affected by an unknown amount the loading equilibrium, and the calculated shearing stresses may be somewhat in error.

SUMMARY OF RESULTS

1. In general, both plug and fillet-welds caused a shortening of the metal at sections across the welds, and a lengthening of the metal between welds. In the plate-and-channel columns, welding caused a shortening of the plate both in the sections across and between welds. The welding strains on the flanges of the columns were low except in *D*1 and *D*2, which were welded on the flanges. The greatest welding strains occurred at about the center of the heavily welded region (welds closely spaced).

2. During column tests, strain lines first appeared on the plates (column types *A*, *B* and *C*) in welded sections, beginning at the edge of the plate and developing inward as the load was increased. No distinct strain line formation occurred between welds or welded sections. The load at which strain lines first appeared corresponded approximately with the load at which the proportional limit in local zones was reached.

3. Welding caused a longitudinal warping or crookedness in all columns. This crookedness due to welding was greatest in the columns which were welded on the flanges (*D*1 and *D*2) and least in the columns with small plug welds (*A*1 and *A*2).

4. The crookedness of the welded columns compared in magnitude with the crookedness of rolled and riveted columns. With two exceptions (*D*1 and *D*2) the crookedness due to welding was considerably less than that which might be expected due to rolling or riveting.

5. The amount of initial crookedness influenced the magnitude of the deflection under load, but the final deflection was not in all cases in the direction of initial crookedness. Since the crookedness of the welded columns is comparable to that of rolled and riveted sections, any effect of the initial crookedness on the ultimate strength of the welded columns should not be classed as purely an effect of welding.

ACKNOWLEDGMENTS

Acknowledgment is made to the Chicago Bridge and Iron Works, which furnished the steel and fabricated the columns for these tests. The writers express their appreciation to Mr. H. C. Boardman, research engineer, and to Mr. Arnold Wessman, of the Chicago Bridge and Iron Works, for their cooperation in the fabrication of the columns; and to Prof. M. O. Withey and Mr. K. F. Wendt, of the University of Wisconsin, for many helpful suggestions.

TYPES of SPECIMENS for TENSION and Bend Tests on Light Metal Welds*

By A. MATTING and H. KLEIN

NO standard testing procedures for light metal welds being in existence, the Welding Research Committee of the German Society of Engineers (VDI) sponsored research on welds in pure aluminum (commercial purity), KS-Seewasser (1.3 Mn, 2.2 Mg, 0.7 Si, 0.2 Sb, rem. Al), Hydronalium Hy 25 (5 Mg, rem. Al) and Elektron Am 503 (1.5–2.0 Mn, 0.3 Si, rem. Mg) 0.08, 0.39 and 0.79 inch thick.

The specimens are shown in Fig. 1, the welds being machined flush. Hydrogen or acetylene with suitable flux was used. The filler rods were of the same composition as base metal. No scarfing was used for 0.08 inch sheet. The 0.39 inch welds were V; the 0.79 inch welds were X. The welded plates were 12 inches in the direction of rolling and 16 inches in the direction of welding.

The welds attained the same strength as full-annealed base metal, Table 1. The more rapidly executed welds in sheet were stronger than those in thicker material. The strength of the Elektron welds was between those of castings and soft annealed sheet. Fracture was sudden and coarse grained, the yield strength of base metal not being attained.

* Abstract of a paper from the Materials and Welding Institute of the Technical College, Hanover, Germany, published in *Autogene Metallbearbeitung*, 31 (13) 205–209, July 1, 1938. Abstracted by G. E. Claussen.

Table 1—Results of Tension Tests

Material	Plate Thickness, Inch	Condition of Base Metal		Tensile Strength, Lb./In.² Specimen A 120 Parallel Section	Tensile Strength, Lb./In.² Specimen A 120 Reduced Section	Specimen A 120 Parallel Section Distance of Fracture from Middle of Weld, Inch	Specimen A 120 Parallel Section Yield Strength, Lb./In.²	Specimen A 120 Parallel Section Elongation, %
Commercially Pure Aluminum	0.08	Hard	Unwelded	22,400	22,000	...	21,000	6.5
Aluminum	0.08	Hard	Welded	11,700–11,800	10,800–11,800	0.24–0.32	7,500	13.6
Aluminum	0.39	Medium hard	Unwelded	17,500	18,900	...	16,100	11.2
Aluminum	0.39	Medium hard	Welded	11,400–11,900	....	0	6,300	18.4
Aluminum	0.79	Soft	Unwelded	13,000	13,000	...	4,600	39
Aluminum	0.79	Soft	Welded	11,200–11,700	11,100–12,200	0–2.6	4,700	30.6
KS-Seewasser (Al-Mg-Mn)	0.08	Hard	Unwelded	45,200	43,400	...	42,000	3.3
"	0.08	Hard	Welded	29,200	31,400–32,400	0.35	19,400	4.0
"	0.39	Medium hard	Unwelded	30,400	32,100	...	26,300	13.6
"	0.39	Medium hard	Welded	25,600–27,200	28,300–28,500	1.2–2.8	11,900	11.8
"	0.79	Medium hard	Unwelded	30,800	32,400	...	21,200	7.5
"	0.79	Medium hard	Welded	24,300–25,300	24,600–26,200	0	15,800	6.1
Hydronalium Hy 25 (Al-Mg)	0.08	Soft	Unwelded	29,300	29,300	...	18,500	19.1
	0.08	Soft	Welded	28,900–29,200	32,200–34,500 (hammered)	0.79	17,200	13.3
"	0.39	Soft	Unwelded	31,300	32,400	...	18,500	21.4
"	0.39	Soft	Welded	25,200–28,200	26,700	0	11,500	14
"	0.79	Soft	Unwelded	27,400	....	...	16,100	....
"	0.79	Soft	Welded	23,700–25,600	25,700–26,900	0	11,800	8.3
Elektron Am 503 (Mg-Mn)	0.08	....	Unwelded	34,400	36,000	...	27,900	5
	0.08	....	Welded	up to 21,300	up to 22,000	0	....	0
"	0.39	....	Unwelded	30,400	32,300	...	25,600	3.7
"	0.39	....	Welded	17,900–22,200	17,200–20,500	0	....	0
"	0.79	....	Unwelded	28,500	28,500	...	....	2.8
"	0.79	....	Welded	15,900–17,900	16,100	0	....	0

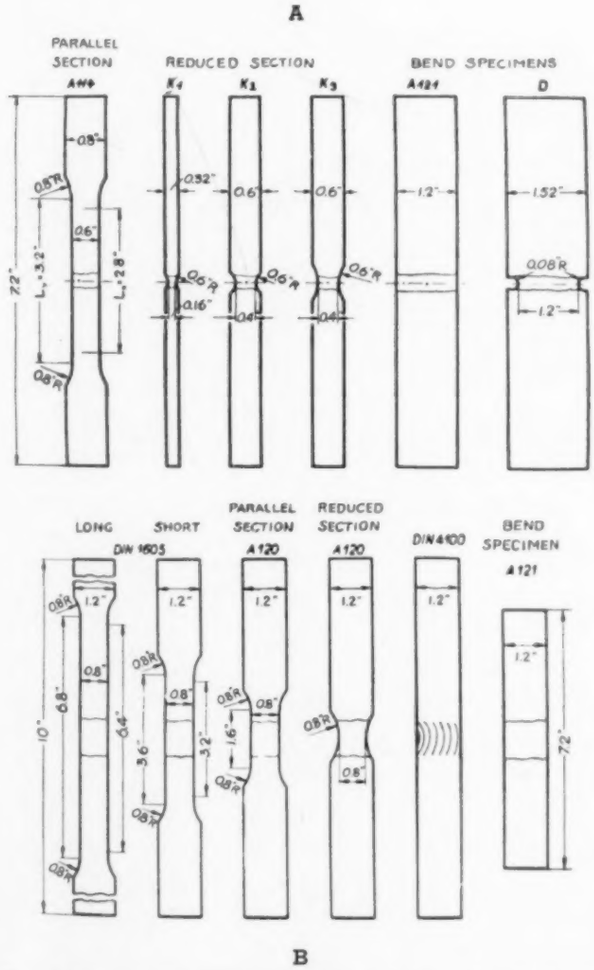


Fig. 1—Specimens for Material (A) 0.08 and (B) 0.39 Inch Thick. (Corresponding Specimens Were Used for Material 0.79 Inch Thick.)

SPECIMENS FOR TESTING THE WELDED JOINT

On the basis of the present tests and those made by Feldmann (Metallwirtschaft, p. 1299, 1937), it is plain that the length of parallel section must be sufficient to permit fracture to develop in the heat-affected zone, which is the weakest part of the joint in Al-Mg-Si and Al-Mn alloys and, if the weld is not machined flush, in pure Al and Al-Mg-Mn alloy as well. Al-Mg alloys may also fracture in the heat-affected zone but Al-Cu-Mg and Elektron alloys always fail in the weld. Even machined welds in Al-Mg-Mn sheet may fail in the heat-affected zone, Fig. 2. Hence, the short or long DIN 1605 specimen is preferable to the A 120 specimen. The width of the specimen should be 2 to $2^1/_2$ times the thickness, Fig. 3.

SPECIMENS FOR TESTING WELD METAL

The specimen shown in Fig. 4 forces fracture in the weld for all thicknesses.

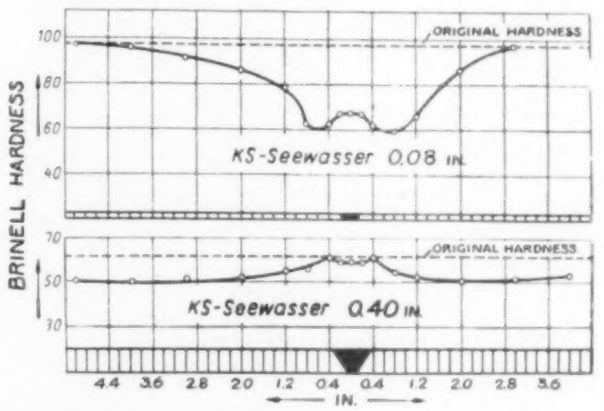


Fig. 2—Brinell Hardness of Welded KS-Seewasser 0.08 and 0.39 Inch Thick. Dotted Line Is Hardness of Unaffected Base Metal

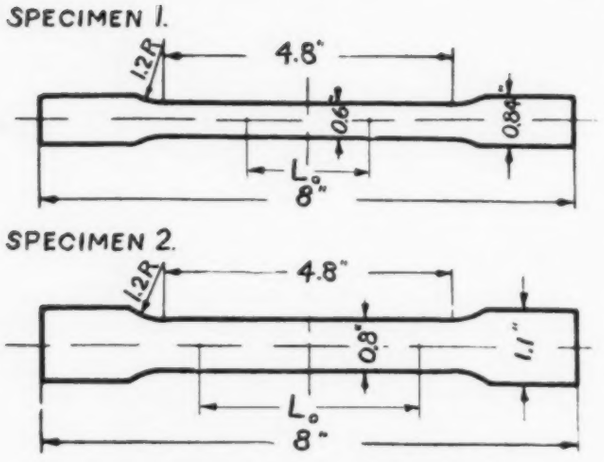


Fig. 3—Specimens for Testing the Welded Joint

Thickness, Inch	Type of Specimen	Length, Inch	Width, Inch	Parallel Length, Inch	Gage Length, Inch
Less than 0.04	1	about 8.7	0.59	about 4.7	1.6
0.04 to less than 0.06	1	about 8.7	0.59	about 4.7	2.0
0.06 to less than 0.08	1	about 8.7	0.59	about 4.7	2.4
0.08 to less than 0.14	2	about 8.7	0.79	about 4.7	3.2
0.14 to less than 0.20	2	about 8.7	0.79	about 4.7	4.0
Over 0.20 to 0.32	2	about 8.7	0.79	about 4.7	2.8
Over 0.32 to 0.39	2	about 8.7	0.79	about 4.7	3.2
Over 0.39	..	about L_o x 100	2 x Thickness	L_o + width	$5.65\sqrt{F_o}$

F_o = Cross section in sq. mm.

YIELD STRENGTH AND ELONGATION

In view of the presence of several zones in welded joints in light alloys, the yield strength (0.2% offset) and elongation are not important. For example, the softened zone may be undesirable, yet the elongation would be unusually high. If the elongation is measured over successive intervals of 0.2–0.4 inch a "step" curve, Fig. 5, may be drawn which is more informative than an over-all measurement.

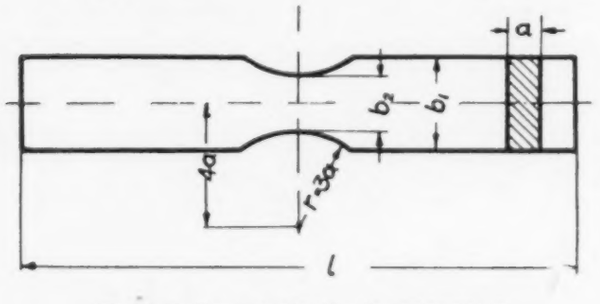


Fig. 4—Specimen for Testing the Weld-Metal

Thickness (a), Inch	Less than 0.24	0.24 and Thicker
l	8.7	9.9
b_1	about 0.59	3 a
b_2	0.39	2 a
r	3 a	3 a

BEND TESTS

Specimen A 121 in Fig. 1 is satisfactory, as shown by the results in Table 2. Since buckling of the bar outside the middle was not observed in light metal welds, the reduced section bend specimen is superfluous. The latter specimen yields 5 to 10° lower bend angles than the unnotched A 121 specimen. The bend test is not considered so good an indication of ductility in light metal welds as the elongation in the tension test. The fracture of the bend specimen is useful in studying porosity, flux inclusions and other defects related to welding technique.

Table 2—Results of Bend Tests

Material	Thickness, Inch	Condition of Base Metal	Bend Angle, Degrees: Unwelded Base Metal A121	Unwelded Base Metal Notched Bar	Weld A121	Weld Notched Bar
Pure Aluminum	0.08	Hard	180	180	180	180
Pure Aluminum	0.39	Medium hard	180	...	180	...
Pure Aluminum	0.79	Soft	180	...	180	...
KS-Seewasser	0.08	Hard	54	46	98	90
KS-Seewasser	0.39	Medium hard	180	...	54	...
KS-Seewasser	0.79	Medium hard	57	...	44	...
Hydronalium (Hy 25)	0.08	Soft	180	180	85	78
Hydronalium (Hy 25)	0.39	Soft	180	...	68	...
Hydronalium (Hy 25)	0.79	Soft	180	...	42	...
Elektron (Am 503)	0.08	....	60	52	19	...
Elektron (Am 503)	0.39	....	28	...	15	...
Elektron (Am 503)	0.79	....	29	...	8	...

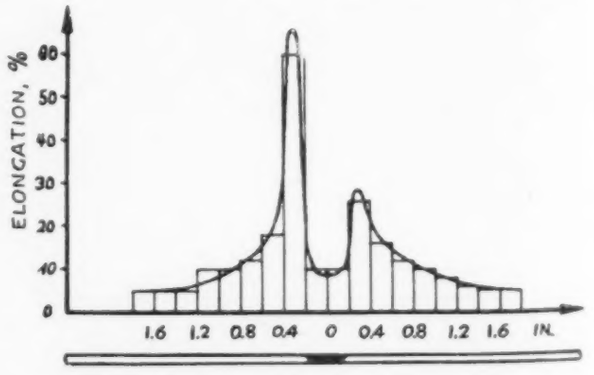


Fig. 5—"Step" Curve of Elongation in Successive Intervals of 0.20 Inch Along a Weld in Pure Aluminum

THE EFFECT OF CURRENT, PRESSURE and Time on the Shear Strength and Structure of Spot Welds in the Aluminum Alloys*

By G. O. HOGLUND and G. S. BERNARD, JR.†

THE spot-welding characteristics of the aluminum alloys, because of their high thermal and electrical conductivity, are quite different from the spot-welding characteristics of many other materials. This difference is manifested, both in the setting of the welding machine, and in the effect of the machine settings on the size and strength of the welds. Spot welds in the aluminum alloys consist of a zone of cast metal, roughly elipsoidal in shape, which is intimately bonded with the unmelted metal of the parts joined. The passage of a highly concentrated electric current through the resistance of the work results in rapid heating and melting of aluminum, and the subsequent solidification of this metal under the pressure of the welding electrodes results in the formation of the weld. The size and strength of this weld is influenced by many factors and it is the object of this paper to show the effect of several of the more important welding variables on the shear strength of spot welds in aluminum alloys.

There are seven variables affecting the shear strength of spot welds in aluminum; three of these are associated with the material welded, and the remaining four are associated with the setting of the welding machine. The three work variables are:

1. Alloy and temper of the material
2. Thickness of the material
3. Condition of the surface of the material

The four machine variables are:

1. The time of duration of welding current
2. The pressure applied to the welding electrodes
3. The current used in making the weld
4. The shape of welding electrode in contact with the work.

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† Aluminum Company of America, New Kensington, Pa.

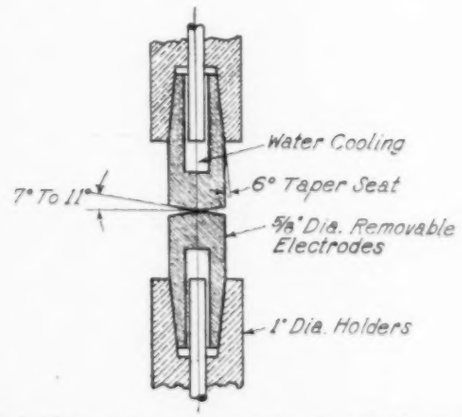


Fig. 1—Electrode Arrangement Used for Spot-Welding Tests

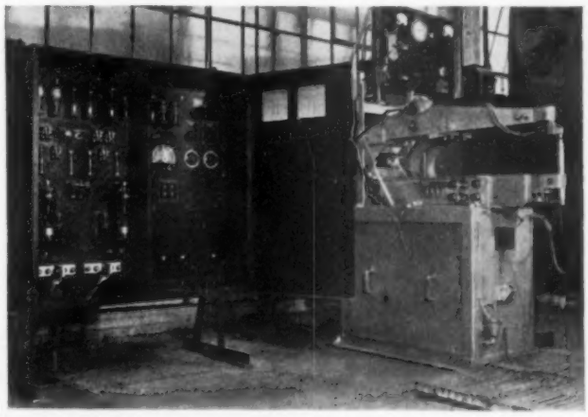
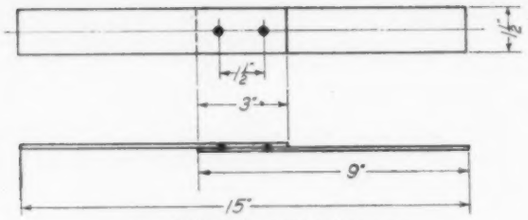


Fig. 2—Spot-Welding Equipment for Welding Aluminum Alloys, Showing Electronic Timing Control

Two of these variables, the condition of the surface of the material welded, and the shape of the welding electrode, are independent of the thickness and grade of the material welded. Consequently it was possible to establish and use throughout the tests the same method of surface preparation and a tip shape that provided consistent pressure and current distribution. All of the specimens were prepared for welding by applying a hydrofluoric acid etch to remove the surface oxide coatings.

The shape of the electrode tip determines the distribution of current and pressure in the weld and this shape must be uniformly maintained if consistent welds are to be obtained. A cone shaped tip shown in Fig. 1 is widely used in production on aluminum alloy parts and was used throughout this investigation.

The general procedure adopted to determine the effect of the welding variables was carried out as follows. The effect of time on shear strength was investigated first for several thicknesses of two of the alloys. On the basis of these tests, times were selected for various thicknesses of material and the subsequent work indicated that the values chosen were suitable for all of the alloys. Welds were then made in several thicknesses of one alloy to determine the effect of current and pressure, and current



For Material .051" & Heavier

Fig. 3—Spot Weld Test Specimen

values and a range of pressure was established for each thickness. Using welding currents suitable for each alloy and thickness, pressures covering the range selected above and the welding times as described above, welds were made on 0.020 inch, 0.032 inch, 0.051 inch, 0.081 inch and 0.125 inch thick materials in each of the aluminum alloys. These last tests were used in determining the strength of welds and the machine settings for the materials shown in Table 2.

DESCRIPTION OF EQUIPMENT

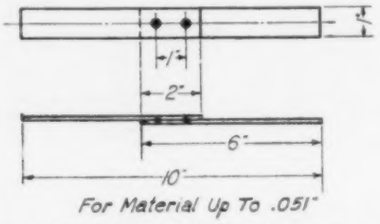
All of the welding described in the paper was performed on an air operated, scissors type welder rated at 200 kva., 440 volts, 60 cycles. The welding transformer, of low-reactance design, delivers a maximum current of 37,400 amperes in a secondary circuit consisting of aluminum channels 36 inches long and spaced at $3^3/_8$ inches. The welding current is adjusted by means of a 5 x 4 tapped autotransformer giving 20 current steps from 5200 amperes to 37,400 amperes. The open circuit secondary voltage varies from 1.73 volts to 13.1 volts.

The welding pressure is adjustable by means of an air storage tank and air regulator. The tip pressure is determined by multiplying the unit air pressure by the area of the air cylinder and the mechanical advantage of the lever system between the tips and the air cylinder.[2] Constant pressure during the weld is insured by delaying the application of welding current one second after applying air to the operating cylinder. The tip pressure is removed approximately 0.1 second after the cessation of welding current.

The welding time is controlled by an electronic weld timer employing sealed off ignitron tubes for the control of primary current supply to autotransformer. This timer, shown in Fig. 2, provides adjustment of the time of current dwell in one-half cycle steps from one-half cycle to thirty cycles. Each alternate weld is started at opposite polarity of welding current to prevent saturation effects when using an odd number of one-half cycles of welding current. The phase angle of ignition of the ignitron tubes is controlled by a heat control dial. This dial was set at 73°, the power factor angle of the welder, so that full sine wave welding current with minimum transient was obtained.

Accurate duplication of welding current and time was insured by the use of a photo-electric device[1] that gave an audible signal if either value changed after starting of welding.

Before any welding was performed the welder was calibrated for value of welding current at each auto-tap setting.[2] A recording time meter was used to check each time setting. Figure 2 shows a typical spot-welding installation for spot-welding aluminum.



For Material Up To .051"

Fig. 4—Spot Weld Test Specimen

DESCRIPTION OF MATERIALS WELDED

By combining other metals with aluminum, alloys are produced to meet the requirements of the varied applications for this material. Commercially pure aluminum may contain up to about 1% of other elements, principally iron and silicon. This material in the annealed condition has excellent forming qualities, but relatively low mechanical properties. The strength may be approximately doubled by cold working. The addition of other metals to form alloys offers another means of increasing the strength and hardness of aluminum. Certain of these aluminum alloys, when subjected to appropriate heat treatment processes, show remarkable increases in tensile and yield strength, and in hardness.

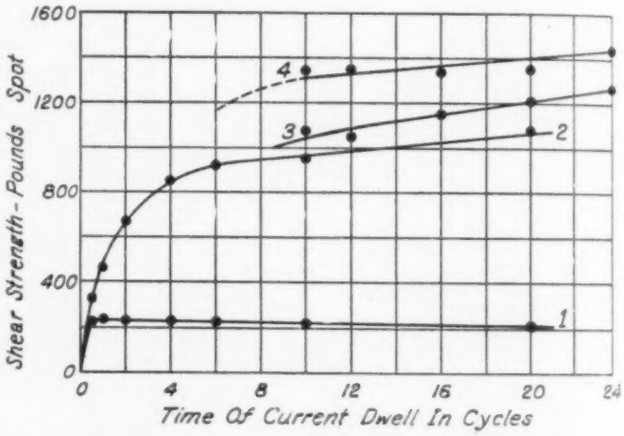


Fig. 5—Effect of Time of Current Dwell on the Shear Strength of Spot Welds in 52S-$^1/_2$H Sheet. All Surfaces Etched. Electrode Tips $^5/_8$ Inch Diam., 7° Cone

Curve No.	1	2	3	4
Sheet thickness	0.021 In.	0.051 In.	0.065 In.	0.080 In.
Welding current	14,000 Amps.	25,400 Amps.	25,400 Amps.	26,800 Amps.
Electrode pressure	200 Lb.	800 Lb.	800 Lb.	800 Lb.

The spot-welding characteristics of aluminum are affected to some degree by the addition of the alloying materials. The strength of the spots is also affected, although not in the same proportion as the strength of the materials welded.

Throughout this paper the materials are referred to by the Aluminum Company of America designation. Composition, mechanical properties and physical properties of the materials welded will be useful to those not familiar with these alloys and are shown in Tables 1, 2 and 3.

TESTING OF WELDS

Spot welds in aluminum possess maximum strength when loaded in static shear. Because of the difficulty in determining accurately the boundary of the welded area after failure and the difficulty of measuring this

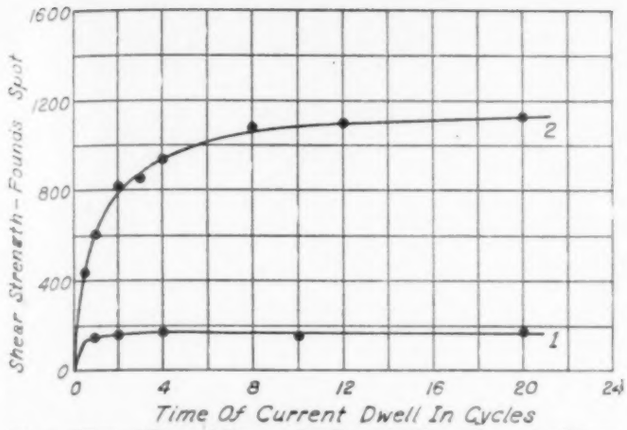


Fig. 6—Effect of Time of Current Dwell on the Shear Strength of Spot Welds in Alclad 24S-T Sheet. All Surfaces Etched. Electrode Tips $^{5}/_{8}$ Inch Diam., 7° Cone

Curve No.	1	2
Sheet thickness	0.020 In.	0.052 In.
Welding current	9200 Amps.	25,400 Amps.
Electrode pressure	200 Lb.	800 Lb.

area, the strength is determined in total load per weld rather than in pounds per square inch of weld area.

The weld specimen used is shown in Figs. 3 and 4. This specimen contains two spots in line and is of sufficient width to develop the full strength of the welds. Spot spacing and edge distance are also sufficient to prevent any significant lowering of weld strength from shunting of welding current or from mushrooming of the spots at the edge of the sheet.

The use of a two-spot specimen minimizes the danger of subjecting the welds to torsional loading in testing. Due to the possibility of the welds not dividing the load equally, the weld strength may be slightly lower than the strength obtained from single-spot specimens. The variation in strength of welds will be reduced somewhat by the averaging effect of two welds.

The two-spot specimens were pulled in an Amsler tension testing machine. A head speed of 0.2 inch per minute was used and is the value generally used in testing aluminum alloy sheet specimens.

Table 1—Nominal Composition of Wrought Aluminum Alloys*

	Per Cent of Alloying Elements. Aluminum and Normal Impurities Constitute Remainder				
Alloy	Copper	Silicon	Manganese	Magnesium	Chromium
2S	...	...	...	...	...
3S	...	...	1.2	...	...
52S	...	...	...	2.5	0.25
53S	...	0.7	...	1.3	0.25
17S	4.0	...	0.5	0.5	...
24S	4.4	...	0.5	1.5	...

* Heat Treatment and cold work symbols omitted since composition does not vary with these factors.

Table 2—Typical Mechanical Properties of Wrought Aluminum Alloys*

Alloy and Temper	Tension Yield Strength (Set = 0.2%) Lb./ Sq. In.	Tension Ultimate Strength Lb./ Sq. In.	Elong. % in 2 In.	Hardness Brinell 500 Kg. 10 Mm. Ball	Shear Shearing Strength Lb./ Sq. In.
2S-O	5,000	13,000	35	23	9,500
2S-$^{1}/_{2}$H	14,000	17,000	9	32	11,000
2S-H	21,000	24,000	5	44	13,000
3S-O	6,000	16,000	30	28	11,000
3S-$^{1}/_{2}$H	18,000	21,000	8	40	14,000
3S-H	25,000	29,000	4	55	16,000
52S-O	14,000	29,000	25	45	18,000
52S-$^{1}/_{4}$H	26,000	34,000	12	62	20,000
52S-$^{1}/_{2}$H	29,000	37,000	10	67	21,000
52S-$^{3}/_{4}$H	34,000	39,000	8	74	23,000
52S-H	36,000	41,000	7	85	24,000
53S-O	7,000	16,000	25	26	11,000
53S-W	20,000	33,000	22	65	20,000
53S-T	33,000	39,000	14	80	24,000
Alclad 17S-T†	33,000	56,000	18	..	32,000
Alclad 24S-T†	41,000	62,000	18	..	40,000

* This table contains only those alloys on which welding tests were made. Other aluminum alloys may be spot welded.

† Alclad material consists of high purity aluminum coating on one or both surfaces and rolled integral with core material. Coating thickness is usually 5.5% of sheet thickness.

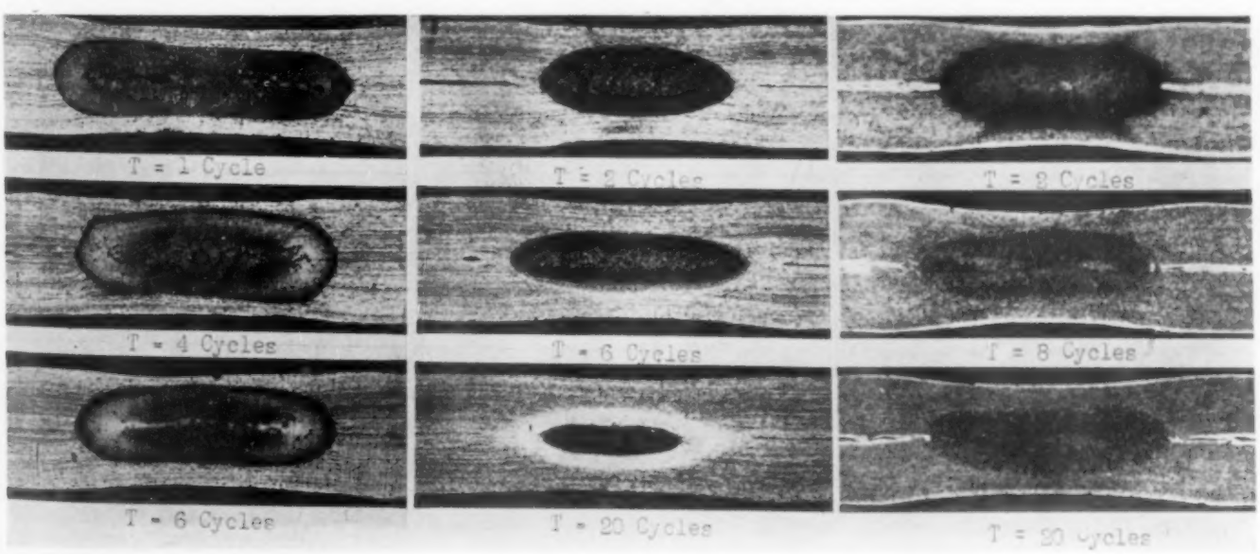


Fig. 7—Microstructure of Spot Welds in 0.020 Inch 52S-$^{1}/_{2}$H, Mag. 10 X I = 10,800 Amps., P = 200 Lb. Tips $^{5}/_{8}$ Inch Diam., 7° Cone

Fig. 8—Microstructure of Spot Welds in 0.051 Inch 52S-$^{1}/_{2}$H, Mag. 5 X I = 25,400 Amps., P = 800 Lb. Tips $^{5}/_{8}$ Inch Diam., 7° Cone

Fig. 9—Microstructure of Spot Welds in 0.051 Inch—Alclad 24S-T, Mag. 5 X I = 25,400 Amps., P = 800 Lb. Tips $^{5}/_{8}$ Inch Diam., 7° Cone

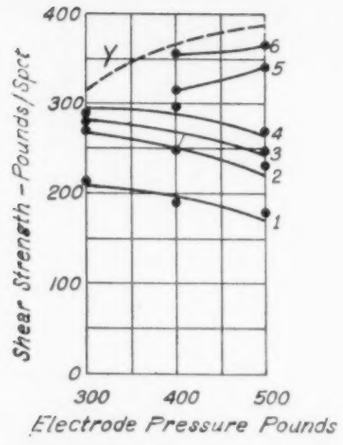


Fig. 10—Effect of Electrode Pressure on the Shear Strength of Spot Welds in 0.025 Inch, 52S-1/2H Sheet. All Surfaces Etched. Tips 1/8 Inch Diam., 7° Cone. T = 6 Cycles

Curve No.	1	2	3
Welding current	13,100 Amps.	15,500 Amps.	16,300 Amps.
Curve No.	4	5	6
Welding current	17,500 Amps.	22,400 Amps.	23,500 Amps.

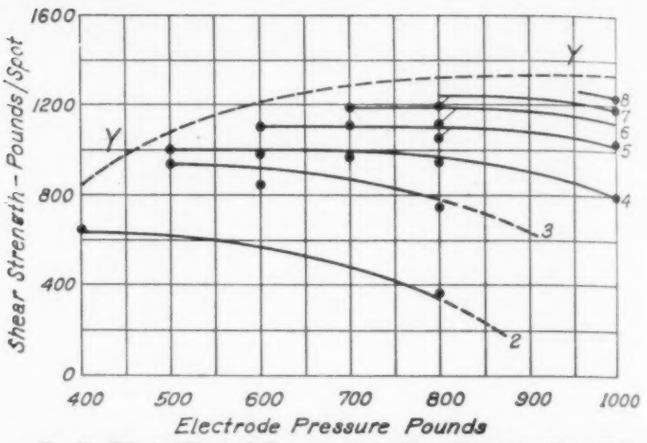


Fig. 11—Effect of Electrode Pressure on the Shear Strength of Spot Welds in 0.052 Inch, 52S-1/2H Sheet. All Surfaces Etched. Tips 1/8 Inch Diam., 7° Cone. T = 10 Cycles

Curve No.	2	3	4	5
Welding current	17,500 Amps.	22,400 Amps.	23,500 Amps.	25,400 Amps.
Curve No.	6	7	8	
Welding current	28,000 Amps.	31,000 Amps.	32,700 Amps.	

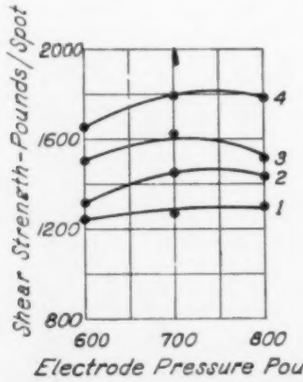


Fig. 12—Effect of Electrode Pressure on the Shear Strength of Spot Welds in 0.081 Inch, 52S-1/2H Sheet. All Surfaces Etched. Tips 1/8 Inch Diam., 7° Cone. T = 12 Cycles

Curve No.	1	2	3	4
Welding current	23,500 Amps.	25,400 Amps.	28,000 Amps.	31,000 Amps.

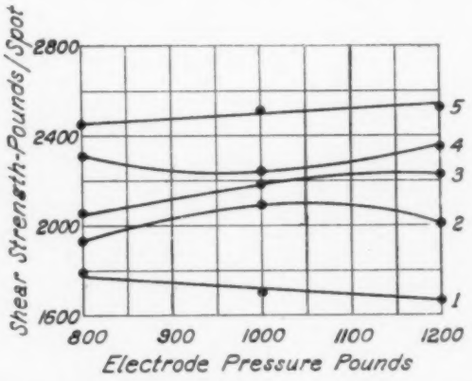


Fig. 13—Effect of Electrode Pressure on the Shear Strength of Spot Welds in 0.126 Inch 52S-1/2H Sheet. All Surfaces Etched. Tips 1/8 Inch Diam., 11° Cone. T = 15 Cycles

Curve No.	1	2	3
Welding current	28,000 Amps.	31,000 Amps.	32,700 Amps.
Curve No.	4	5	
Welding current	34,600 Amps.	36,000 Amps.	

Table 3—Properties of Wrought Alloys

Material	Specific Gravity	Electrical Conductivity Per Cent of International Copper Standard	Thermal Conductivity at 100° C. C.G.S. Units
Commercially pure aluminum	2.71	59	0.54
Copper alloy welding tip material	8.77	85	0.82
Copper	8.89	100	0.918
Structural steel	7.85	15	0.14
Stainless steel 18–8	7.97	2	0.04
Aluminum alloys:			
2S-O	2.71	59	0.54
2S-1/2H	2.71	57	0.52
2S-H	2.71	57	0.52
3S-O	2.73	50	0.45
3S-1/2H	2.73	41	0.38
3S-H	2.73	40	0.37
52S-O	2.67	40	0.37
52S-1/4H	2.67	40	0.37
52S-1/2H	2.67	40	0.37
52S-3/4H	2.67	40	0.37
52S-H	2.67	40	0.37
53S-O	2.69	45	0.41
53S-W	2.69	40	0.37
53S-T	2.69	40	0.37
17S-T	2.79	30	0.28
24S-T	2.77	30	0.28

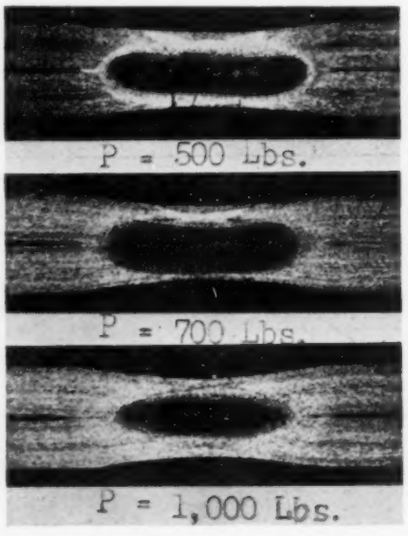


Fig. 14—Microstructure of Spot Welds in 0.081 Inch, 52S-1/2H, Mag. 5 X T = 10 Cycles, I = 23,500 Amps. Tips 1/8 Inch Diam., 7° Cone

Failure on the shear test occurred either by shearing in the welds or by pulling buttons from one of the sheets. All 0.020-inch material and 0.032-inch material in 2S-O, 2S-½H, 2S-H and 3S-O failed by pulling buttons. All heavier gage material failed by shear in the welds.

At each machine setting, five duplicate specimens were made. The shear tests covered in this paper represent about 700 combinations of the five welding variables and 90% of these settings produced welds with a maximum strength variation less than 20% from the average of five duplicate specimens. If proper choice of machine setting is made, all thicknesses from 0.020 inch to ⅛ inch of all of the aluminum alloys can be spot welded with a maximum shear strength variation less than 20% from the average for welds made at that machine setting.

In addition to the shear strength test, welds at all machine settings were examined for weld size, appearance and "pickup" of aluminum on the tips. These factors were also considered in choosing final values for recommended machine settings. Other tests such as impact or fatigue tests on individual welds were not considered in drawing these conclusions in order to simplify an already complicated test program. Further tests on spot-welded structures are being conducted to ascertain the strength under static, fatigue and impact loading of spot welds made at the machine settings that gave the best results in these tests.

Fig. 15—Microstructure of Spot Welds in 0.125 Inch, 2S Aluminum, Mag. 1 X. T = 15 Cycles, I = 37,400 Amps. Tips ½ Inch Diam., 11° Cone

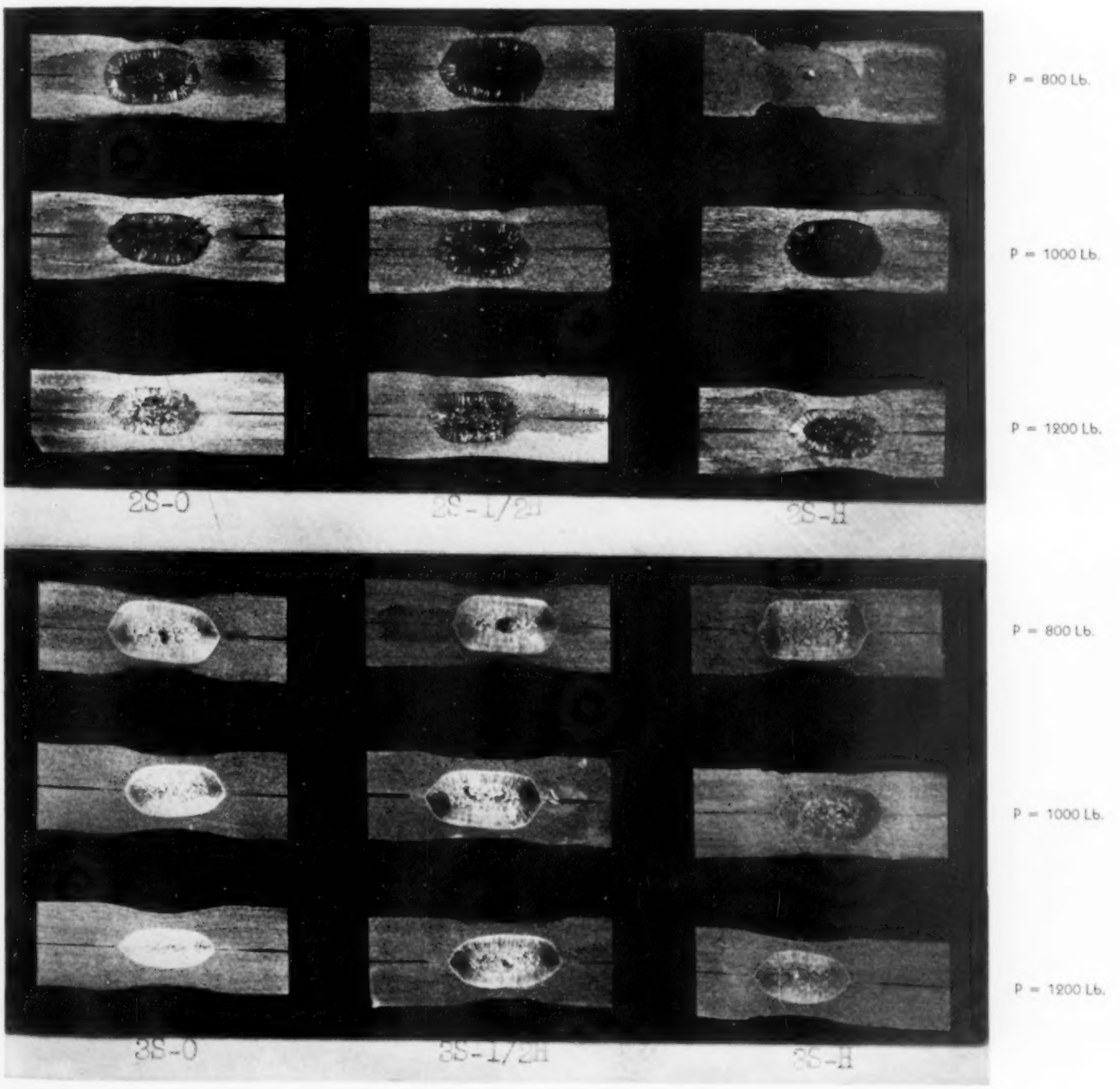


Fig. 16—Microstructure of Spot Welds in 0.125 Inch, 3S Aluminum, Mag. 1 X. T = 15 Cycles, I = 36,000 Amps. Tips ½ Inch Diam., 11° Cone

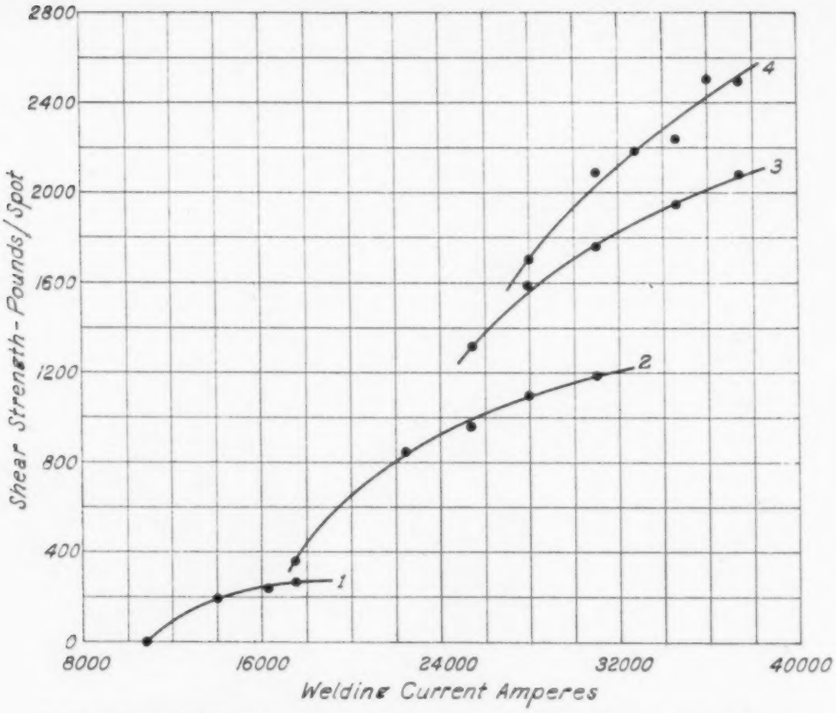


Fig. 17—Effect of Welding Current on the Shear Strength of Spot Welds in 52S-1/2H Sheet

Curve No.	1	2	3	4
Sheet thickness	0.021 In.	0.051 In.	0.101 In.	0.126 In.
Time	6 Cycles	10 Cycles	12 Cycles	15 Cycles
Pressure	400 Lb.	800 Lb.	900 Lb.	1000 Lb.
Tips 5/8 Inch Diam.	7° Cone	7° Cone	7° Cone	11° Cone

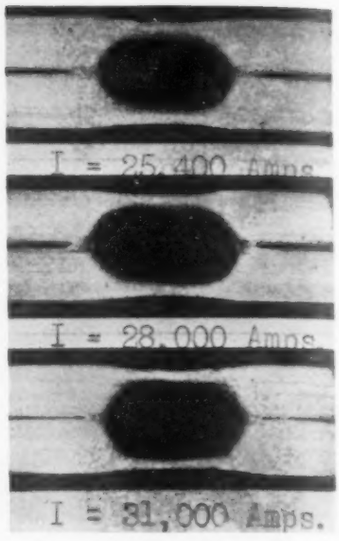


Fig. 19—Microstructure of Spot Welds in 0.102 Inch—52S-1/2H, Mag. 2.5 X

T = 12 Cycles, P = 900 Lb.
Tips 5/8 Inch Diam., 7° Cone

THE EFFECT OF TIME

Aluminum alloys are generally spot welded with the time of current dwell less than 1/2 second or 30 cycles on a 60 cycle per second power supply. The value of time used will vary with the thickness of material welded. Times as low as 1/2 cycle or less are used on very thin material such as 0.002-inch aluminum foil. The timer used in these tests, permitted accurate duplication of the time of current dwell in steps of 1/2 cycle.

The heat effect of the current increases as the weld time is increased, and size and strength of the weld is also increased. Tests to determine the effect of time on weld strength were performed on 0.020 inch, 0.051 inch, 0.064 inch and 0.081 inch 52S-1/2H sheet and on 0.016 inch, 0.020 inch and 0.051 inch Alclad 24S-T. A welding pressure of 200 pounds was used on the 0.016-inch and 0.020-inch material and a welding pressure of 800 pounds was used on the heavier material. Welds were made at varying time from 1/2 to 24 cycles. These tests were made at a number of values of welding current covering the entire range over which each material could be welded.

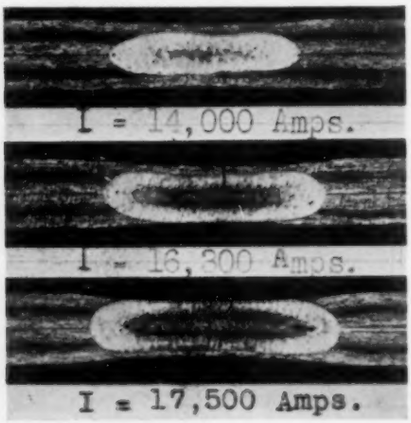


Fig. 18—Microstructure of Spot Welds in 0.020 Inch—52S-1/2H, Mag. 10 X

T = 6 Cycles, P = 400 Lb.
Tips 5/8 Inch Diam., 7° Cone

The shape of the shear strength *vs.* time of current dwell curve is similar for each thickness of material regardless of the value of welding current. The strength rises rapidly with increasing time until an approximately constant strength is reached. Further increase in time results in very little increase in weld strength. The time at which this constant strength is reached is 1/2 to 3 cycles for 0.020-inch material, and 6 to 8 cycles for 0.051-inch material. The heavier materials show a slight increase in strength up to 24 cycles. Several of these curves are shown in Figs. 5 and 6. The use of higher or lower values of welding current results in higher or lower weld strength at each time setting, the effect of time, however, is independent of the welding current except at current values which result in a very small weld. At these low currents, which would not be used in production, the weld strength reaches the flat portion of the curve at somewhat longer timing than those shown.

Welds made at various values of welding time were examined microscopically to determine the effect of time of current dwell on the size and structure of the welds. A transverse section through the center of the weld was polished and etched to show the weld structure. These sections indicate clearly the extent of the cast

weld zone and the soundness of the weld structure. Examination of a large number of these sections show that after a time, depending on the thickness of the material, the cast weld zone reaches a constant size and that further application of welding current does not materially increase this size. This fact is demonstrated in Figs. 7, 8 and 9.

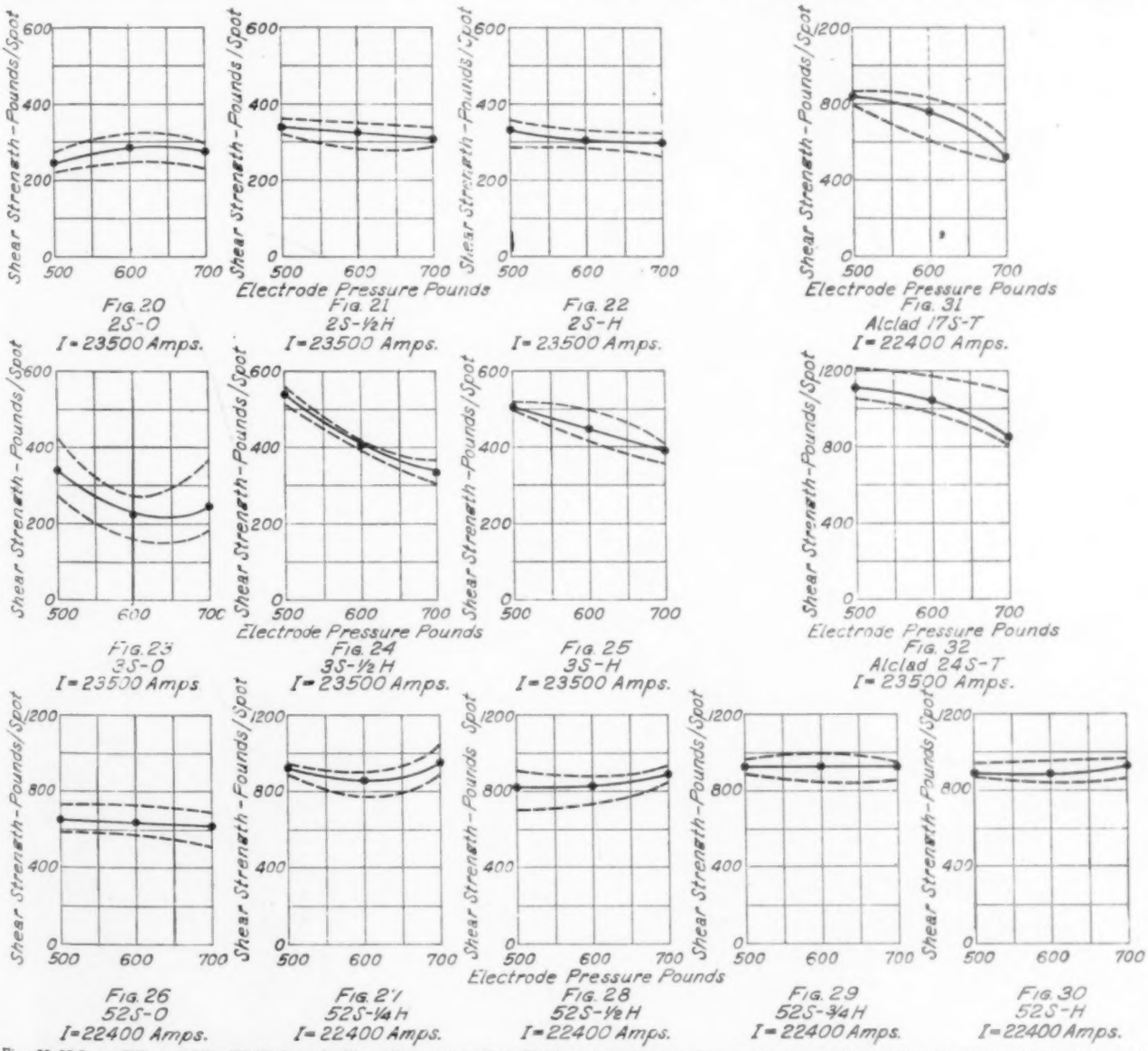
Figure 7 shows some porosity in welds made at 1 cycle and at 4 cycles while a sound weld is obtained with 6 cycles. In 0.051-inch material welds made at 6 cycles or less show porosity at the higher values of welding current.

Spot welds in aluminum alloys appear to reach their full size in a very short time. After reaching this size, the current density and heat generated in the weld are so lowered that the water cooled tips conduct heat away with sufficient rapidity to prevent further melting. The ultimate size of the weld is determined by the welding current and is not a function of time if sufficiently long times are used. The use of time somewhat longer than that necessary to reach maximum size, probably keeps the metal in a molten state long enough for the welding tips to squeeze the sheets and close up any pores present.

Table 4—Machine Settings for Spot-Welding Aluminum Alloys

B & S Gage No.	Gage In.	Time Cyc.	Tip Shape 5/8 In. Diam. Cone Angle	Welding Current (Amperes) Alloys Welded 2S-O to 2S-H	3S-1/4H to 3S-H	52S to 53S-W 53S-T	Alclad 24S-T	Electrode Pressure Min. Lb.	Electrode Pressure Max. Lb.
26	0.016	4	7°	15,000	14,000	13,500	14,500	200	350
24	0.020	6	7°	16,000	15,000	15,000	16,000	250	400
22	0.025	6	7°	17,500	16,000	16,000	17,500	300	450
20	0.032	8	7°	19,000	18,000	18,000	19,000	350	500
18	0.040	8	7°	21,000	19,500	19,500	21,000	425	600
16	0.051	10	7°	23,000	22,000	22,000	23,000	525	700
14	0.064	10	7°	26,000	24,500	24,500	26,000	600	800
12	0.081	12	7°	29,000	27,000	27,500	29,000	700	900
10	0.102	12	7°	32,500	30,000	31,000	32,000	800	1050
8	0.128	15	11°	36,000	33,000	34,000	35,000	900	1200

In continuing this investigation to determine the effect of other welding variables, the times of current dwell shown in Table 4 have been used. These values


Shear Strength - Pounds/Spot
Electrode Pressure Pounds
Fig. 20 2S-O I = 23500 Amps.
Fig. 21 2S-½H I = 23500 Amps.
Fig. 22 2S-H I = 23500 Amps.
Fig. 31 Alclad 17S-T I = 22400 Amps.
Fig. 23 3S-O I = 23500 Amps
Fig. 24 3S-½H I = 23500 Amps.
Fig. 25 3S-H I = 23500 Amps.
Fig. 32 Alclad 24S-T I = 23500 Amps.
Fig. 26 52S-O I = 22400 Amps.
Fig. 27 52S-¼H I = 22400 Amps.
Fig. 28 52S-½H I = 22400 Amps.
Fig. 29 52S-¾H I = 22400 Amps.
Fig. 30 52S-H I = 22400 Amps.

Figs. 20–32 Inc.—Effect of Alloy Welded on the Shear Strength of Spot Welds in 0.051 Inch Aluminum Sheet 2 S Material Not Etched, All Other Materials Etched Before Welding. Tips 5/8 Inch Diam., 7° Cone. Time = 10 Cycles. Dashed Curves Show Range of Shear Strength for Five Duplicate Specimens

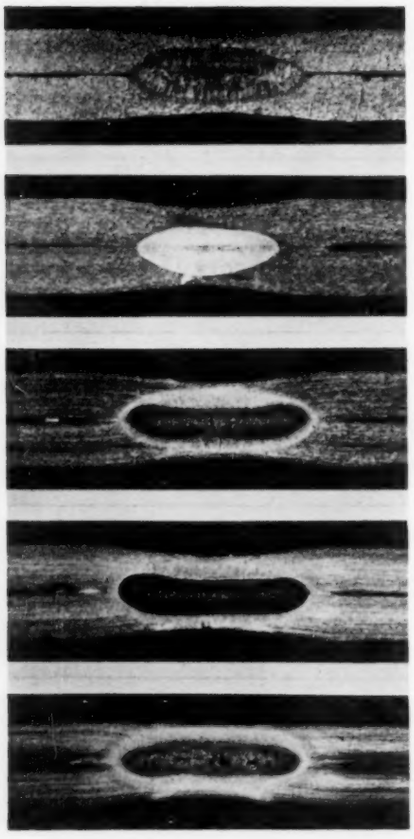


Fig. 33—Microstructure of Spot Welds in 0.051 Inch Aluminum, Mag. 5X. T = 10 Cycles, P = 600 Lb. Tips 1/8 Inch Diam., 7° Cone

have been found to produce good welding results without any difficulty other than increasing the heating in certain parts of the welding machine and in the work.

If the speed of welding is less than 60 welds per minute and the welding tips are adequately cooled, "pickup" of aluminum onto the welding tips is not increased by the use of these times, compared to shorter time. "Pickup" also seems to be a function of welding current rather than time of current dwell.

The fact that small changes in time of current dwell, from the values given in Table 4, does not materially change the strength of the weld, indicates that absolute accuracy of weld time is not an essential for welding aluminum.

EFFECT OF WELDING CURRENT AND ELECTRODE PRESSURE

In spot-welding aluminum a number of combinations of welding current and electrode pressure may be used to produce satisfactory welds. The value of welding current used is the principal factor in determining the ultimate size and strength of the weld. The electrode pressure has some effect on the size and strength of the weld, but a much greater effect on the appearance and soundness of the weld.

Welds made in seven different thicknesses of 52S-1/2H aluminum at values of current and pressure covering the range of setting used for each thickness were made and the shear strength measured. The effect of electrode pressure on shear strength is shown in Figs. 10, 11, 12 and 13. At the lower values of welding current the strength of the welds is decreased with increasing electrode pressure, while at the higher values of welding current the strength of the welds is increased slightly

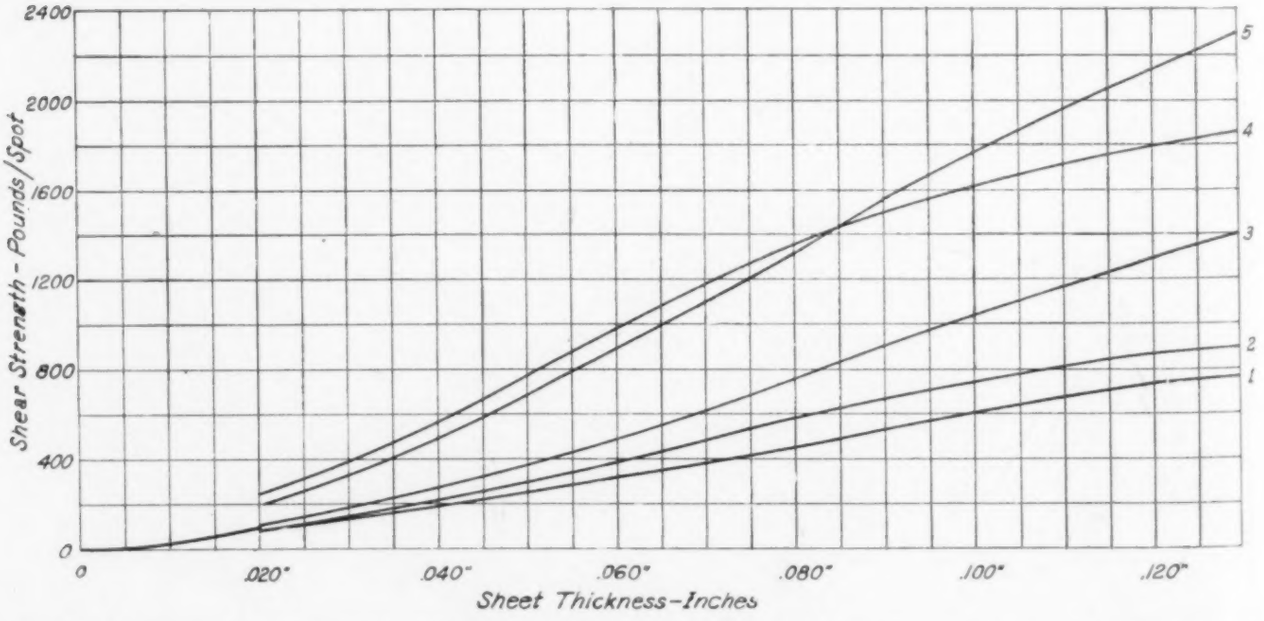


Fig. 34—Effect of Sheet Thickness and of Alloy Welded on the Shear Strength of Spot Welds in Aluminum. (See Table 4 for Machine Settings Used on Each Alloy)

Curve No.	Alloy and Temper
1	2S-O
2	2S-1/4H to 2S-H
3	3S-1/4H to 3S-H
4	Alclad 24S-T
5	52S-1/4H to 52S-H, 53S-W, 53S-T

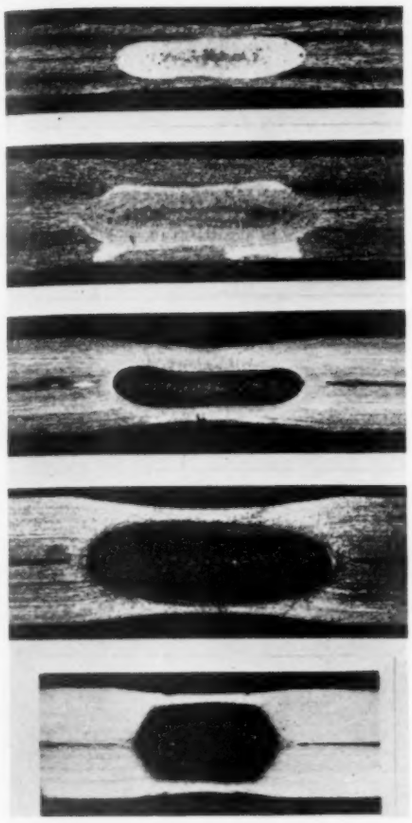

0.020 Inch, T = 6 Cycles
I = 14,000 Amps.
P = 400 Lb., Mag. 10 ×
0.032 Inch, T = 8 Cycles
I = 17,500 Amps.
P = 500 Lb., Mag. 10 ×
0.051 Inch, T = 10 Cycles
I = 25,400 Amps.
P = 600 Lb., Mag. 5 ×
0.064 Inch, T = 10 Cycles
I = 25,400 Amps.
P = 800 Lb., Mag. 5 ×
0.102 Inch, T = 12 Cycles
I = 31,000 Amps.
P = 900 Lb., Mag. 2.5 ×

Fig. 35—Microstructure of Spot Welds in 52 S = $^1/_2$H. Tips $^1/_4$ Inch Diam., 7° Cone

with increasing electrode pressure. At intermediate values of welding current there is a considerable range of pressure over which welds of nearly constant strength may be obtained. It is within this range of pressure that the best welding results are obtained.

At each value of electrode pressure there is a maximum current which can be used before "blowup" of the weld results. This maximum current and the maximum strength obtainable in the welds increases with increase in electrode pressure. Curve *Y* in Figs. 10 and 11 show the approximate maximum weld strength that can be obtained at each pressure.

The effect of welding current on the shear strength of welds in several thicknesses of 52S-$^1/_2$H is shown in Fig. 17. The strength of the welds increases in almost direct proportion to the welding current. Each curve is for one thickness of material and for one value of electrode pressure and time of current dwell. Curves of similar shape and slope were obtained when other values of pressure and time were used.

Both the welding current and the electrode pressure affect the appearance of spot welds in aluminum. Best appearance is obtained with low currents and high pressures. These conditions are conducive to low weld strength so that the final setting must be a compromise. If the current and pressure are adjusted so that the cast weld zone does not extend to the outside sheet surfaces, good weld strength can be obtained and the appearance of the welds will be satisfactory for most applications.

Figures 14, 15 and 16 show sections of spot welds made at several values of welding pressure. At the low values of pressure the welds show some porosity and cracking. This defect is reduced or eliminated by going to a higher welding pressure. The size of the cast zone is also reduced at the highest values of electrode pressure.

Figures 18 and 19 show sections of welds made at various values of welding current. The size of the weld increases with the welding current and some porosity and cracking is present at the high values of welding current. The cast zone increases both in diameter and penetration into the sheet as the current is increased. Best appearance and improved corrosion resistance are obtained if the cast zone does not extend to the sheet surface. Thus, the maximum weld strength and value of welding current are limited to those at which the cast zone is confined within the outside sheet surfaces.

Welding electrode tips used on aluminum alloys are made from a copper alloy and at the machine settings which must be used to obtain strong welds, there is a tendency for aluminum from the weld to alloy with the copper tip. This "pickup" of aluminum by the copper tip will occur even when the cast weld zone does not extend to the sheet surface. The "pickup" is a result of local heating at the point of contact between the welding tip and the aluminum sheet, and increases progressively as welding proceeds, i.e., after from 10 to 30 welds it is sufficient to affect the appearance of the outside of the sheet. Most of the "pickup" occurs during the first $^1/_2$ cycle of current conduction at which time the current density is very high because of the small area of contact between the tip and the sheet. Increasing welding pressure, or decreasing welding current will reduce the amount of "pickup" on the tips. These expedients, also, reduce the size and strength of the weld, and consequently cannot be applied to eliminate "pickup" entirely.

Continued welding without cleaning the welding tips results in forcing the copper aluminum alloy into the copper tip and the formation of cracks in the tip surface. In subsequent welds the presence of "pickup" results in additional local heating in the weld and the lower melting point constituents in the sheet material may be forced out to the sheet surface under the tip. When this occurs, "pickup" onto the tip increases rapidly and continued welding may result in a "blow up" of the weld. On the other hand this condition can be controlled by removing the "pickup" with a fine grade of abrasive cloth after 20 to 30 welds.

EFFECT OF SHEET THICKNESS AND OF ALLOY WELDED

The tests to determine the effect of time, current and pressure were performed with 52S-$^1/_2$H aluminum alloy. Tests were also made on Alclad 24S-T and the results obtained permitted the conclusion that the range of machine settings found suitable for 52S-$^1/_2$H could be used on other aluminum alloys.

In order to determine more accurately the machine settings to be used for each alloy, welds were made in 0.020-inch, 0.032-inch, 0.051-inch, 0.081-inch and 0.125-inch sheet of each of the alloys listed in Table 2. These welds were made using tip shapes and times shown in Table 4 and at three values of electrode pressure covering the range of pressure given in Table 4. The welding current used was varied for each alloy, the values used being approximately those given in Table 4.

Figures 20 to 32 show the results of shear strength measurements for the 0.051-inch sheet. The effect of the temper of the material welded is shown in a comparison of Figs. 20 to 22, Figs. 23 to 25 and Figs. 26 to 30. Welds in the fully annealed materials show a lower strength than welds in materials which have been cold worked. There is no noticeable difference in the strength of welds in materials with various degrees of cold work.

A comparison of welds made in various alloys discloses considerable difference in the strength of the welds, the stronger alloys producing the stronger welds. The strength of the welds does not bear a definite ratio to the strength of the material welded, however.

Cross sections of several welds in different materials are shown in Figs. 15, 16 and 33. The size and structure of the welds are approximately the same for all alloys. In Fig. 16, the smaller size of welds obtained in 3S-O material compared to welds in 3S-$^1/_2$H and 3S-H made at the same machine setting should be noted. This indicates the need for slightly higher welding currents or lower welding pressures for welding annealed materials and partially accounts for the lower strengths obtained on welds in annealed material.

Figure 35 shows sections of spot welds in various thicknesses of 52S-$^1/_2$H sheet. The machine settings used in making these welds is approximately the same as given in Table 4 for 52S. The diameter of the cast zone in proportion to sheet thickness is considerably larger for the thin material than for the thick material. This accounts for the fact that the strength of the weld increases approximately as the 1.4th power of sheet thickness, rather than as the square of sheet thickness. The amount of porosity is greater in welds in the thicker material than in thinner material. It has not been possible to entirely eliminate all porosity in heavy gage material by using longer times or higher pressures and still maintain good weld strength.

In choosing recommended machine settings for each alloy consideration was given to variation in strength at various pressures, the appearance and size of the weld and the relation of strength and machine settings for the various thicknesses of material. Settings were chosen so that both weld strength and machine settings, when plotted against sheet thickness gave smooth curves.

The average shear strength of spot welds in a number of aluminum alloys is given in Fig. 34. The strengths given are those that will be obtained when using the machine settings listed in Table 4. No test data are given since these curves were calculated from tests made at currents which differed somewhat from those finally chosen in Table 4.

The current values given in Table 4 are about the maximum that can be used without extending the cast-weld zone to the sheet surface. Since the tapped transformer winding may not permit current steps smaller than 2000 amperes it may be necessary to weld at currents as low as 90% of the values shown. This will reduce the weld strength: a 10% reduction in weld current resulting in a 15 to 20% reduction in weld strength. Since there may be a strength variation as much as 15 to 20%, the minimum weld strength may be 30 to 35% below the average values given in Fig. 34. Settings which produce welds of lower strength than this should not be used as the weld strength may be very inconsistent.

CONCLUSIONS

The shear strength of spot welds in aluminum alloys is influenced by each of the seven welding variables discussed in the introduction. For the production of strong welds the proper choice of the value of welding current is of primary importance. The use of low values of welding current is the most frequent cause of weld failure in spot-welded aluminum construction. This is partly a result of too much emphasis by the inspection department on appearance of the outside surfaces or by the welding operator on a machine setting which will allow the maximum number of welds to be made without cleaning off the welding tips. The production of strong welds with good appearance requires frequent dressing of the welding tips and settings which produce more than 30 welds without "pickup" on the welding tips, should be suspected of producing weak welds.

The time of current dwell and the electrode pressure must also be properly adjusted and controlled if dependable results are to be obtained. Uniform shape of the welding tip, since it affects current density in the weld, is as important as the choice of welding current. Removal of the oxide coating from the surface to be welded is not essential for spot welding all of the alloys. Alloys 2S and 3S can usually be welded without any surface preparation. The amount of oxide coating present on the other alloys increases "pickup" of aluminum onto the tips to such an extent that it is probably more economical to remove the oxide coating from the outside surfaces than to accept the lowered production rates incident to frequent tip cleaning.

While the data on shear strength of spot welds in various aluminum alloys given in Fig. 34 are not intended for use in design of spot-welded joints an examination of these data will disclose the fact that for production of maximum efficiency of welded joints, the arrangement and spot spacing will vary both with the alloy welded and the thickness of the sheet. Work is now in progress to determine proper spot arrangement and design information for spot-welded aluminum construction which will be reported at a later date.

In closing, one fact should be emphasized. A great many of the welds on which shear strength is given would not be satisfactory welds for use, mainly because of their poor appearance. The data given in Table 4 and in Fig. 34 are for welds of good appearance and should prove useful in production welding of aluminum alloys. The chance for error in calibrating welding equipment and the differences in various lots of material are sufficient that a production setup based on the recommended settings outlined in this report must be checked by frequent inspection of the welds during the welding operations.

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2. Measurement of the Spot Welding Machine Variables, by G. S. Bernard, Jr., THE WELDING JOURNAL, March 1938, **17**, No. 3, page 23.

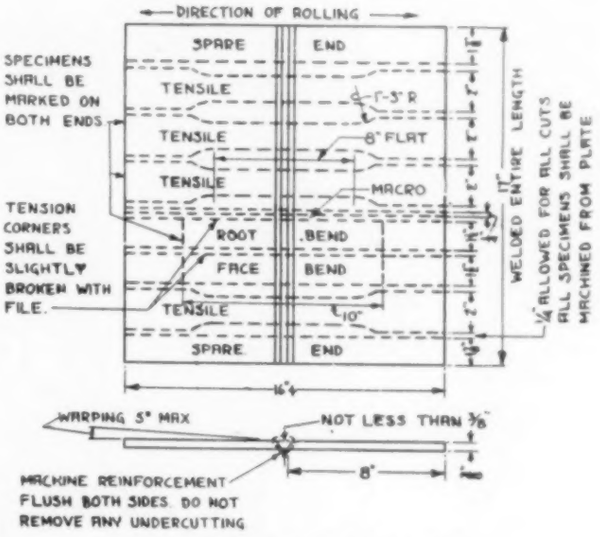
AN INVESTIGATION OF ARC AND Gas Welded Joints in Aluminum and Aluminum Alloys*

By LIEUT. COMDR. R. K. WELLS (C C) U. S. N.
and A. G. BISSELL†

THE early history of aluminum welding is not a matter of formal record. However, it is known that about 1907 considerable experimenting was done using the hydrogen flame in air to weld aluminum parts without the use of a flux. In 1909, the first aluminum welding job of any size was attempted on some chemical tanks. The welds were made by burning hydrogen in air without the use of a flux and expensive and relatively unsound joints resulted. About 1911, a welding flux was developed and substantially improved results were obtained. In 1911 and 1912, the first field-welded job was undertaken. This was the gas welding of some large aluminum pans. About this same time the first welded aluminum beer tanks were fabricated. The adoption of welding as a method of fabricating steam jacketed kettles and cooking utensils did much to further develop the welding of aluminum.

It was not until about 1930 that any substantial progress was made in the application of arc welding to the joining of aluminum and aluminum alloy parts. Arc welding became practicable with the development of a flux for coating electrodes which made it possible to deposit the electrode material uniformly and essentially free from oxide contamination.

For a long time, the properties of welded joints in aluminum and its alloys were not well known. Most applications were made by trial and error, with little actual knowledge of the strength of the joints, or of their other characteristics. The Bureau of Construction and Repair of the Navy Department therefore sponsored an investigation into the welding properties of a number of commercially available aluminum alloys whose use in marine applications had been suggested. With the cooperation of the producer of the material, more than 60 specimens were welded, both with gas and with the arc, and the materials under test were carefully analyzed and the test results tabulated.



LAYOUT OF WELDED TEST PLATES
FIG. 2

Some of the specimens contained joints welded into two plates of identical composition. Others had welds joining two different materials. Welds were made in both the flat and vertical positions wherever possible. As it was found that joints between different materials quite generally behaved like joints in the weaker of the two base components, consideration here of composite joints will not be attempted. Results obtained with two plates of the same base material only will be presented.

In making the welds with gas both acetylene and oxy-hydrogen were used. Some difficulty was experienced in getting uniformly satisfactory results using the oxyacetylene process but with oxyhydrogen quite consistent results were obtained.

While joints of equal strength were produced in the vertical and flat positions by either gas process, satisfactory vertical welds were not obtained in this investigation using the arc. It is understood that arc welding is being used successfully in the vertical position in some shops.

The materials used in this investigation are listed in

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† Senior Welding Engineer, Bureau of Construction and Repair, U. S. Navy Department.

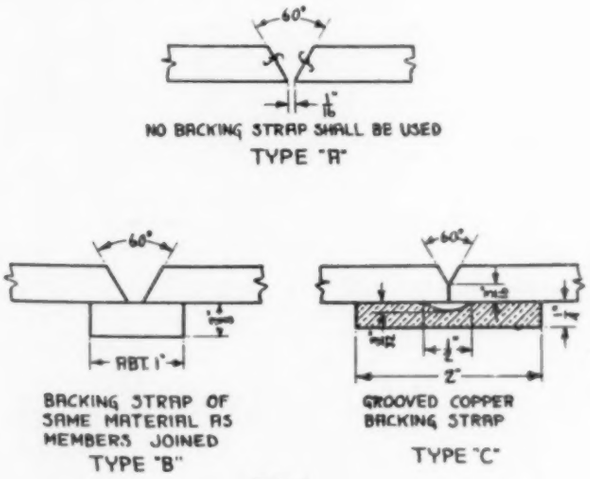


FIG. 1

Table 1

Commercial Designation	Alloy Combination	Physical Condition	Chemical Composition								
			Al	Mg	Mn	Ti	Fe	Si	Cr	Cu	Ni
No. 2S	Commercially Pure Aluminum	As-Rolled	99.13	..	0.02	..	0.70	0.14	..	0.01	..
No. 3S	Aluminum Manganese	As-Rolled	98.15	0.02	1.02	0.01	0.49	0.20	..	0.11	..
No. 52S	Aluminum Magnesium Chromium	As-Rolled	96.87	2.57	0.01	0.01	0.20	0.07	0.26	0.01	..
No. 53SO	Aluminum Magnesium Silicon Chromium	Annealed	97.55	1.35	0.01	0.01	0.20	0.58	0.27	0.03	..
No. 53SW	Aluminum Magnesium Silicon Chromium	Quenched	...	..	..	..	..	..	..	..	..
No. 53ST	Aluminum Magnesium Silicon Chromium	Heat Treated	...	..	..	..	..	..	..	..	..
No. 43	Aluminum 5% Silicon	As-Cast	94.56	0.01	0.01	0.12	0.47	4.79	..	0.04	..
No. 195AC	Aluminum Copper	As-Cast	94.34	0.01	0.01	0.01	0.65	0.53	..	4.45	..
No. 195T4	Aluminum Copper	Heat Treated	...	..	..	..	..	..	..	..	..
No. 214	Aluminum Magnesium	As-Cast	95.56	3.80	0.01	0.01	0.23	0.13	..	0.26	..
No. 356AC	Aluminum Silicon Magnesium	As-Cast	93.13	0.29	0.01	0.01	0.49	5.95	..	0.02	0.10
No. 356T4	Aluminum Silicon Magnesium	Heat Treated	...	..	..	..	..	..	..	..	..
Type D—2S	Filler Material No. 1	Wire	99.21	..	0.01	0.01	0.71	0.03	..	0.03	..
Type E—43S	Filler Material No. 2	Wire	94.96	0.01	0.02	0.02	0.49	4.84	..	0.01	..

Table 1 together with their average chemical compositions.

All of the plates used were $^3/_8$ x 8 x 17 inches. Each one was beveled on one 17-inch edge to form the joints shown in Fig. 1. The 60° single-V joint was used for all of the welded joints. The open V without a backing strip shown by Type *A* was used for all gas-welded joints while Type *B* with a backing strip of the material being welded and Type *C* with a grooved copper backing strip were used for the arc-welded specimens.

The plates to be gas welded had the root face of the joint nicked about $^1/_{16}$ inch deep at about $^1/_4$-inch intervals with a cold chisel to aid in obtaining complete fusion of this edge. Before starting to weld the root opening of the joint was spaced $^1/_{16}$ inch at one end and $^1/_4$ inch at the other end. Welding from the narrow end toward the center, a two-inch tack was made, then another two-inch tack was put in at the other end which had drawn up to give a uniform root opening. Then the first layer was completed. In putting in the second layer, welding was started about 5 inches from one end and completed to that end. The finish was made from the beginning of the first weld to the opposite end.

The joints to be arc welded were clamped tightly to the backing strips with a $^1/_8$-inch root opening. One end was tacked and the first layer started from the opposite end, welding toward the tack using a $^3/_{16}$-inch fluxed electrode in the case of the Type *B* joint. The second layer was put in with a $^1/_4$-inch electrode using a slightly lower current in most cases and welding in the same direction removing the slag of the former pass only sufficiently to strike the arc. The Type *C* joint using a copper backing strip having a groove $^1/_2$ inch wide and $^3/_{32}$ inch deep immediately behind the root opening was welded in one pass using $^1/_4$-inch electrodes.

After the welding was completed the backing strip of the material being welded and the reinforcements were removed by machining to the same thickness as the original plate and 4 tensile and 2 bend specimens were prepared as shown in Fig. 2. The tensile specimens were pulled in a 20,000 pound testing machine and the root and face bends were made in a guided bend jig shown in Fig. 3.

This guided bend test has been used for some time by the Navy in connection with the welding operators qualification tests and has recently been adopted by the AMERICAN WELDING SOCIETY in its Standard Qualification Procedure. It is a most searching test, forcing the bend to occur in the weld and contiguous material exposing defects more successfully than other test methods that have been used.

The tensile strength, yield point, elongation in 2 inches and angles of bend were determined on the original materials as received, and these values are noted for comparison with the results obtained from the welded joints.

Macrographs made of sections of each joint are shown with the tabulated data. X-ray examination was also made of the macro sections and the findings noted.

The accompanying tabulations give the results of the investigation.

CONCLUSIONS

It is not proposed to offer these results as final and conclusive, because it is realized that the number of specimens tested was quite limited. They are merely offered in evidence of what we feel is perhaps the optimum obtainable at present, since the joints were made with great care by a skilled welder of wide experience with aluminum and its alloys. It is hoped that others may reproduce or extend these tests, so that other evidence may be obtainable to confirm or modify our present opinions.

From the present series of tests the following conclusions as to the weldability of the various aluminum alloys seem reasonably to be indicated.

Commercially Pure Aluminum (2S)

This material is weldable by both gas and arc processes. The heat of welding tends to anneal the material in and adjacent to the weld, giving rise to decreased strength after welding. The loss of strength is more pronounced with gas than with arc welding. In the present series of tests, the filler rod used for the gas welds

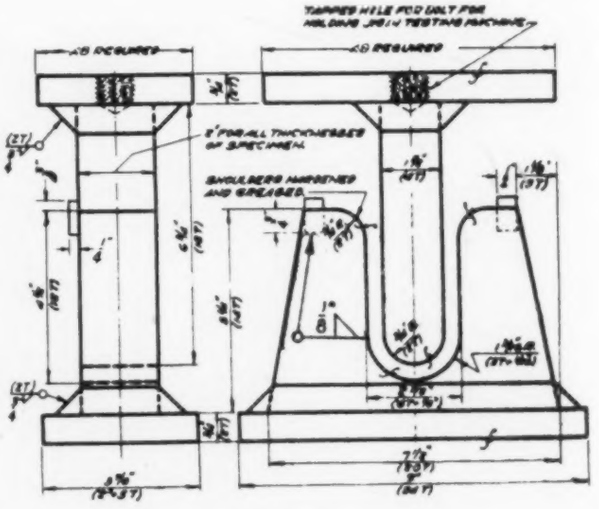


FIG. 3

COMMERCIALLY PURE ALUMINUM (2S) - GAS WELDED

WELDING PROCESS:	OXY-ACETYLENE.
TIP SIZE:	NO. 8A.
ACETYLENE PRESSURE:	10 LBS.
OXYGEN PRESSURE:	13 LBS.
GAS MIXTURE:	EXCESS ACETYLENE.
FILLER MATERIAL:	NO. 1, 1/4".
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL (AS ROLLED)

TENSILE STRENGTH:	16540 PSI.
YIELD POINT:	13375 "
ELONGATION:	33% IN 2".
BEND:	180°.

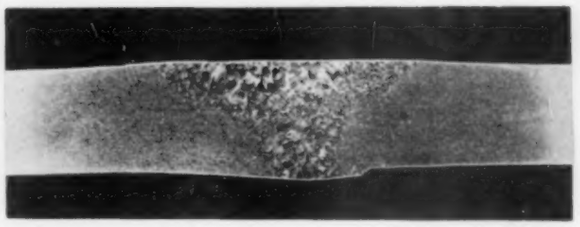
WELDED JOINT

12750	PSI FAILURE IN WELD.
12490	" " " "
13600	" " " PARENT METAL.
13000	" " " "
12762	" AVERAGE TENSILE STRENGTH

ROOT BEND: 180°
FACE BEND: 180°

X-RAY: CLEAR.

EFFICIENCY OF WELDED JOINT: 77.15% IN TENSILE STRENGTH.



COMMERCIALLY PURE ALUMINUM - (2S) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 36 V. 430 A.
SECOND PASS:	1/4" ELECTRODE. 30 V. 250 A.
PLATE THICKNESS:	3/8"
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL (AS ROLLED)

TENSILE STRENGTH:	16540 PSI.
YIELD POINT:	13375 "
ELONGATION:	33% IN 2".
BEND:	180°.

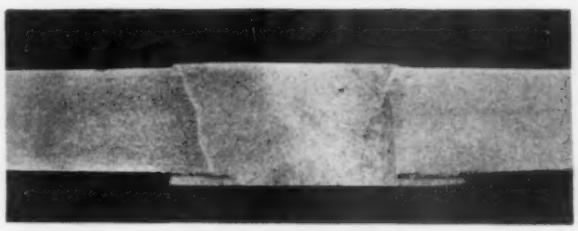
WELDED JOINT

14220	PSI. FAILURE IN PARENT METAL.
14400	" " " "
14190	" " " FUSION ZONE.
12320	" " " "
13832	" AVERAGE TENSILE STRENGTH.

ROOT BEND: 55° FUSION ZONE
FACE BEND: 180°

X-RAY: SOME POROSITY.

EFFICIENCY OF WELDED JOINT: 83.62% IN TENSILE STRENGTH.



COMMERCIALLY PURE ALUMINUM - (2S) - ARC WELDED.

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
ONE PASS:	1/4" ELECTRODE. 30 V. 360 A.
PLATE THICKNESS:	3/8"
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	GROOVED COPPER.

ORIGINAL MATERIAL (AS ROLLED)

TENSILE STRENGTH:	16540 PSI.
YIELD POINT:	13375 "
ELONGATION:	33% in 2".
BEND:	180°.

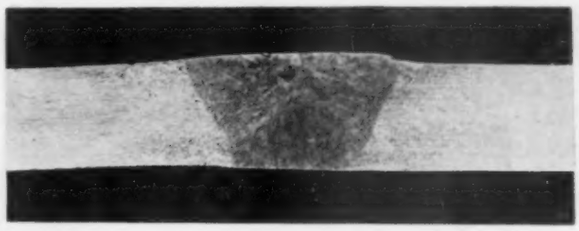
WELDED JOINT

14000	PSI. FAILURE IN PARENT METAL.
14160	" " " " "
14300	" " " " "
14670	" " " " "
14277	" AVERAGE TENSILE STRENGTH.

ROOT BEND: 180°.
FACE BEND: 180°.

X-RAY: CLEAR.

EFFICIENCY OF WELDED JOINT: 87.5% IN TENSILE STRENGTH.



ALUMINUM MANGANESE ALLOY - (3S) - GAS WELDED

WELDING PROCESS:	OXY-ACETYLENE.
TIP SIZE:	NO. 8A.
ACETYLENE PRESSURE:	10 LBS.
OXYGEN PRESSURE:	13 LBS.
GAS MIXTURE:	EXCESS ACETYLENE.
FILLER MATERIAL:	NO. 1, 1/4".
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL (AS ROLLED)

TENSILE STRENGTH:	18900 PSI.
YIELD POINT:	13620 "
ELONGATION:	34% IN 2".
BEND:	180°.

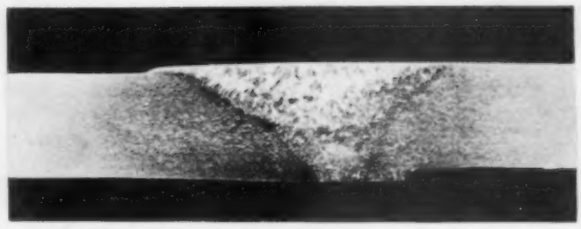
WELDED JOINT

14150	PSI. FAILURE IN WELD.
14880	" " " "
15190	" " " "
14100	" " " "
14577	" AVERAGE TENSILE STRENGTH

ROOT BEND: 180°.
FACE BEND: 180°.

X-RAY: CLEAR.

EFFICIENCY OF WELDED JOINT: 77.1% IN TENSILE STRENGTH.



ALUMINUM MANGANESE ALLOY - (3S) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2".
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 34 V. 380 A.
SECOND PASS:	1/4" ELECTRODE. 30V. 240A.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL (AS ROLLED)

TENSILE STRENGTH:	18900 PSI.
YIELD POINT:	13620 "
ELONGATION:	34% IN 2".
BEND:	180°.

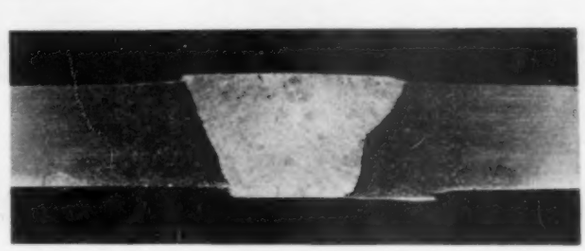
WELDED JOINT.

16000	PSI. FAILURE IN FUZION ZONE.
16770	" " " " "
16800	" " " " "
17110	" " " " "
16670	" AVERAGE TENSILE STRENGTH.

ROOT BEND: 180°.
FACE BEND: 180°.

X-RAY: SLIGHT POROSITY.

EFFICIENCY OF WELDED JOINT: 88.2% IN TENSILE STRENGTH.



ALUMINUM MANGANESE ALLOY - (3S) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 30V. 320A.
SECOND PASS:	1/4" ELECTRODE. 31 V. 300 A.
PLATE THICKNESS:	3/8".
BACKING STRIP:	GROOVED COPPER.

ORIGINAL MATERIAL (AS ROLLED)

TENSILE STRENGTH:	18900 PSI.
YIELD POINT:	13620 "
ELONGATION:	34% IN 2".
BEND:	180°.

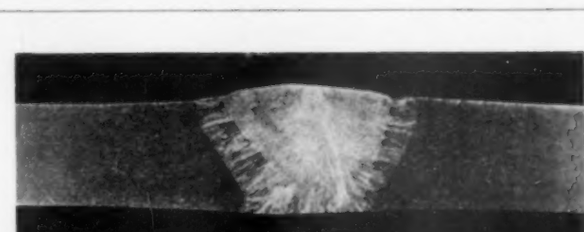
WELDED JOINT

16800	PSI. FAILURE IN PARENT METAL.
16820	" " " " "
16840	" " " " "
17260	" " " " "
16855	" AVERAGE TENSILE STRENGTH.

ROOT BEND: 180°
FACE BEND: 180°

X-RAY: SLIGHT POROSITY AT TOP.

EFFICIENCY OF WELDED JOINT: 89.1% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM CHROMIUM ALLOY - (52S) - GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE:	11 LBS.
OXYGEN PRESSURE:	10 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2, 1/4".
FLUX:	WASTE PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL
(AS ROLLED)

TENSILE STRENGTH: 28550 PSI.
YIELD POINT: 25260 "
ELONGATION: 17% IN 2".
BEND: 180°.

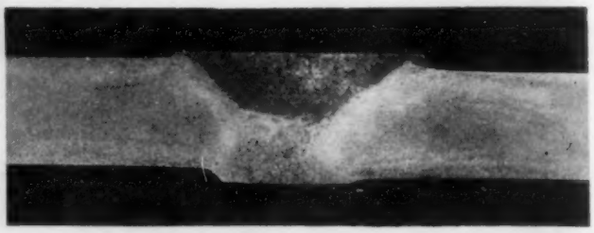
WELDED JOINT

22180 PSI. FAILURE IN WELD.
21100 " " " "
23270 " " " "
22183 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 10° FAILED IN WELD.
FACE BEND: 24° " " FUSION ZONE

X-RAY: SLIGHTLY POROUS.
TRANSITION ZONE MELTING.

EFFICIENCY OF WELDED JOINT: 76.9% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM CHROMIUM - (52S) - GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE	12 LBS.
OXYGEN PRESSURE:	10 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 1, 1/4".
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL
(AS ROLLED)

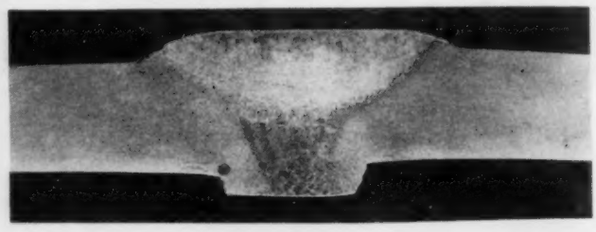
TENSILE STRENGTH: 28550 PSI.
YIELD POINT: 25260 "
ELONGATION: 17% IN 2".
BEND: 180°

18250 PSI. FAILED IN WELD, GAS HOLES
14570 " " " " " "
12600 " " " " " "
17650 " " " " " "
15612 " AVERAGE TENSILE STRENGTH.

X-RAY: POROUS, SLAG AND TRANSITION ZONE MELTING.

ROOT BEND: 28°
FACE BEND: 31-1/2°.

EFFICIENCY OF WELDED JOINT: 55.3% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM CHROMIUM ALLOY - (52S) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	5/16" ELECTRODE. 35 V. 370 A.
SECOND PASS:	1/4" ELECTRODE. 30 V. 250 A.
PLATE THICKNESS:	3/8"
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL
(AS ROLLED)

TENSILE STRENGTH: 28550 PSI.
YIELD POINT: 25260 "
ELONGATION: 17% IN 2".
BEND: 180°.

25200 PSI. FAILED IN WELD.
24000 " " " " SLAG.
16840 " " " "
18590 " " " "UNDERCUT.
21157 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 22-1/2° FAILED IN WELD.
FACE BEND: 6° " " GAS HOLE.

X-RAY: POROUS.

EFFICIENCY OF WELDED JOINT: 73.4% IN TENSILE STRENGTH.

ALUMINUM MAGNESIUM CHROMIUM ALLOY - (52S) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
ONE PASS:	1/4" ELECTRODE. 30 V. 350 A.
PLATE THICKNESS:	3/8".
BACKING STRIP:	GROOVED COPPER.

ORIGINAL MATERIAL
(AS ROLLED)

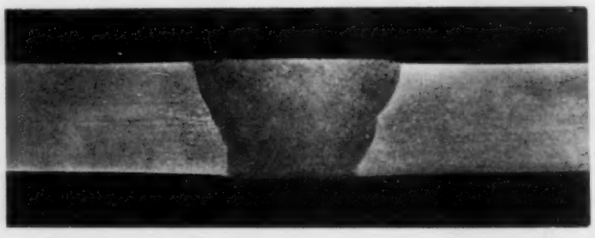
TENSILE STRENGTH: 28550 PSI.
YIELD POINT: 25260 "
ELONGATION: 17% IN 2".
BEND: 180°.

26750 PSI. FAILURE IN WELD - SLAG.
25800 " " " " AND FUSION ZONE.
27400 " " " "
28450 " " " FUSION ZONE.
27100 " AVERAGE TENSILE STRENGTH.

X-RAY: SLIGHT POROSITY.

ROOT BEND: 24° FAILED IN WELD.
FACE BEND: 17-1/2° " " "

EFFICIENCY OF WELDED JOINT: 94.5% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM SILICON CHROMIUM ALLOY - (53S) - GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE:	10 LBS.
OXYGEN PRESSURE:	9 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2, 1/4".
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL
(ANNEALED)

TENSILE STRENGTH: 14380 PSI.
YIELD POINT: 6075 "
ELONGATION: 46% IN 2".
BEND: 180°.

14800 PSI. FAILED IN PARENT METAL.
14680 " " " " "
15000 " " " " "
15280 " " " " "
14940 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 36.5° FAILED IN WELD.
FACE BEND: 46.5° FAILED IN WELD.

X-RAY: SLIGHT POROSITY.

EFFICIENCY OF WELDED JOINT: 103% IN TENSILE STRENGTH.

ALUMINUM MAGNESIUM SILICON CHROMIUM ALLOY - (53S) - ARC WELDED.

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 32V. 370A.
PLATE THICKNESS:	3/8".
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL
(ANNEALED)

TENSILE STRENGTH 14380 PSI.
YIELD POINT: 6075 "
ELONGATION: 46% IN 2".
BEND: 180°.

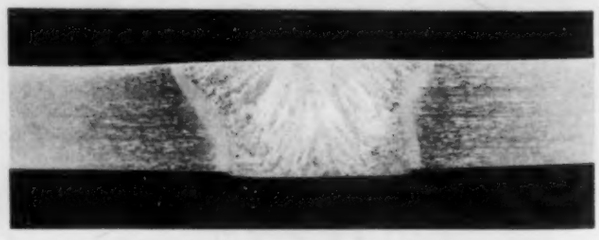
WELDED JOINT

14200 PSI. FAILED IN PARENT METAL.
14550 " " " " "
14350 " " " " "
14540 " " " " "
14410 " AVERAGE TENSILE STRENGTH.

X-RAY: SLIGHTLY POROUS.

ROOT BEND: 8° FAILED IN WELD.
FACE BEND: 180°.

EFFICIENCY OF WELDED JOINT: 100.2% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM SILICON CHROMIUM ALLOY - (53SO)
ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
ONE PASS:	3/16" ELECTRODE. 32V. 370A.
PLATE THICKNESS:	3/8"
BACKING STRIP:	GROOVED COPPER.

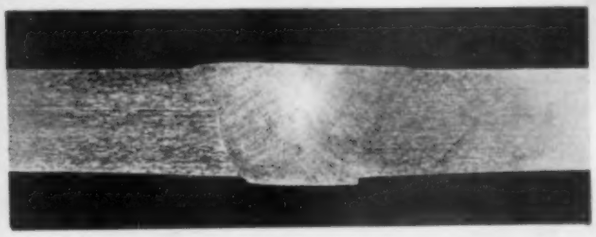
ORIGINAL MATERIAL
(ANNEALED)
TENSILE STRENGTH: 14380 PSI.
YIELD POINT: 6075 "
ELONGATION: 46% IN 2".
BEND: 180°.

WELDED JOINT
14600 PSI. FAILED IN PARENT METAL.
14550 " " " " "
14620 " " " " "
14580 " " " " "
14587 " AVERAGE TENSILE STRENGTH.

X-RAY: SLIGHT POROSITY

ROOT BEND: 180°.
FACE BEND: 180°.

EFFICIENCY OF WELDED JOINT: 101.4% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM SILICON CHROMIUM ALLOY - (53SW)- ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
ONE PASS:	1/4" ELECTRODE. 30V. 340A.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	GROOVED COPPER.

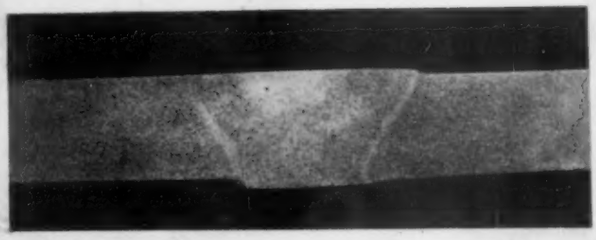
ORIGINAL MATERIAL
(QUENCHED)
Tensile STRENGTH: 34650 PSI.
YIELD POINT: 21900 "
ELONGATION: 30% In 2".
BEND: 160°

WELDED JOINT
26900 PSI. FAILED IN WELD.
24700 " " " "
26050 " " " PARENT METAL.
27130 " " " WELD.
26145 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 17.5° FAILED IN WELD.
FACE BEND: 34.5° " " "

X-RAY: POROUS.

EFFICIENCY OF WELDED JOINT: 75.45% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM SILICON CHROMIUM ALLOY (53ST)-GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE:	7 LBS.
OXYGEN PRESSURE:	10 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

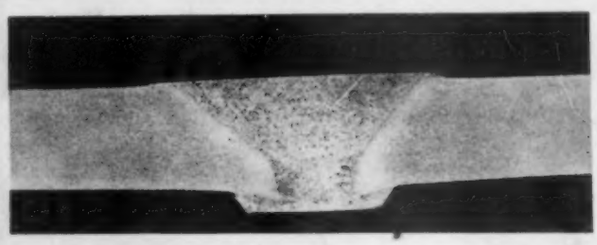
ORIGINAL MATERIAL
(HEAT-TREATED AND AGED)
TENSILE STRENGTH: 36500 PSI.
YIELD POINT 29500 "
ELONGATION: 24% IN 2".
BEND: 180°

WELDED JOINT
14190 PSI. FAILED IN WELD.
8920 " " " "
20230 " " " PARENT METAL.
21000 " " " "
16085 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 28° FAILED IN WELD.
FACE BEND: 34° FAILED IN WELD.

X-RAY: POROUS.

EFFICIENCY OF WELDED JOINT: 44.06% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM SILICON CHROMIUM ALLOY - (53ST)- ARC WELDED

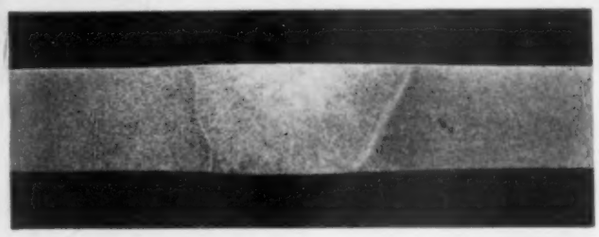
WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 35V. 360A.
SECOND PASS:	1/4" ELECTRODE. 30V. 250A.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL
(HEAT TREATED AND AGED)
TENSILE STRENGTH: 36500 PSI.
YIELD POINT: 29500 "
ELONGATION: 24% IN 2".
BEND: 180°.

WELDED JOINTS
24700 PSI. FAILED IN WELD-SLAG.
24430 " " " PARENT METAL.
23420 " " " WELD-SLAG.
24660 " " " PARENT METAL
24302 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 24° FAILED IN WELD.
FACE BEND: 19° " " "

EFFICIENCY OF WELDED JOINT: 66.5% IN TENSILE STRENGTH.



ALUMINUM 5% SILICON ALLOY - (43) - GAS WELDED.

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE:	13 LBS.
OXYGEN PRESSURE:	12 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2.
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL
(AS CAST)
TENSILE STRENGTH: 18950 PSI
YIELD POINT: 10825 "
ELONGATION: 3% IN 2"
BEND: 17°

WELDED JOINT
15870 PSI. Failed IN PARENT METAL.
13870 " " " " "
14070 " " " " "
16060 " " " " "
14942 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 36° FAILED IN PARENT METAL
FACE BEND: 27° " " "

X-RAY: SLIGHT POROSITY.

EFFICIENCY OF WELDED JOINT: 78.8% IN TENSILE STRENGTH.

ALUMINUM 5% SILICON ALLOY - (43) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 36V. 380A.
SECOND PASS:	1/4" ELECTRODE. 30V. 250A.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	SAME AS PLATE.

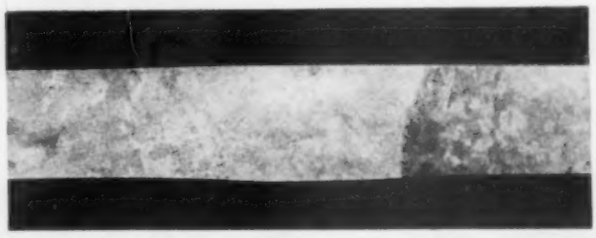
ORIGINAL MATERIAL
(AS CAST)
TENSILE STRENGTH: 18950 PSI.
YIELD POINT: 10825 "
ELONGATION: 3% IN 2"
BEND: 17°

WELDED JOINT
14450 PSI. FAILED IN PARENT METAL
13940 " " " " "
13550 " " " " "
14000 " " " " "
13985 " AVERAGE TENSILE STRENGTH

ROOT BEND: 27° FAILED IN PARENT METAL
FACE BEND: 19° " " "

X-RAY: SLIGHT POROSITY.

EFFICIENCY OF WELDED JOINT: 73.7% IN TENSILE STRENGTH



ALUMINUM MAGNESIUM ALLOY - (214) - GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE	12 LBS.
OXYGEN PRESSURE:	11 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2.
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL (AS CAST)

TENSILE STRENGTH: 17065 PSI.
YIELD POINT: 11400 "
ELONGATION: 4% IN 2".
BEND: 30°.

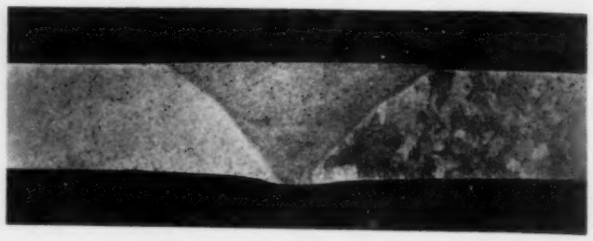
WELDED JOINT

16040 PSI. FAILED IN PARENT METAL
17200 " " " FUSION ZONE.
13330 " " " PARENT METAL
16830 " " " "
15975 AVERAGE TENSILE STRENGTH.

ROOT BEND: 10° FAILED IN WELD.
FACE BEND: 13.5° " " "

X-RAY POROUS.

EFFICIENCY OF WELDED JOINT: 83.0% IN TENSILE STRENGTH.



ALUMINUM MAGNESIUM ALLOY - (214) - ARC WELDED.

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 35V. 375A.
SECOND PASS:	1/4" ELECTRODE. 30V. 400A.
PLATE THICKNESS:	3/8".
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL (AS CAST)

TENSILE STRENGTH: 17065 PSI.
YIELD POINT: 11400 "
ELONGATION: 4% IN 2".
BEND: 30°.

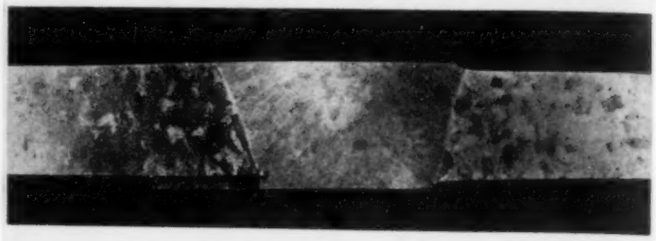
WELDED JOINT

17600 PSI. FAILURE IN PARENT METAL
20100 " " " " "
15770 " " " " "
15170 " " " " "
17160 " AVERAGE TENSILE STRENGTH

X-RAY:

ROOT BEND: 10° FAILUPE IN WELD
FACE BEND: 14° " " PARENT METAL.

EFFICIENCY OF WELDED JOINT: 100.5% IN TENSILE STRENGTH.



ALUMINUM SILICON MAGNESIUM ALLOY - (356AC) - GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO.11.
HYDROGEN PRESSURE:	13 LBS.
OXYGEN PRESSURE:	12 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2.
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL (AS CAST)

TENSILE STRENGTH: 22175 PSI.
YIELD POINT: 14570 "
ELONGATION: 25% IN 2".
BEND: 13.5°

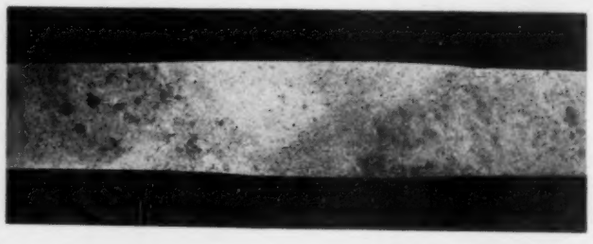
WELDED JOINT

16700 PSI. FAILED IN PARENT METAL
17720 " " " " "
18920 " " " " "
19030 " " " " "
18092 PSI. AVERAGE TENSILE STRENGTH

ROOT BEND: 29° FAILED IN FUSION ZONE.
FACE BEND: 34° " " WELD.

X-RAY: SLIGHT POROSITY.
PLATE MATERIAL POROUS.

EFFICIENCY OF WELDED JOINT: 81.58% IN TENSILE STRENGTH.



ALUMINUM SILICON MAGNESIUM ALLOY - (356AC) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 35V. 375A.
SECOND PASS:	30V. 250A.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL (AS CAST)

TENSILE STRENGTH: 22175 PSI.
YIELD POINT: 14570 "
ELONGATION: 2.5% IN 2".
BEND: 13.5°.

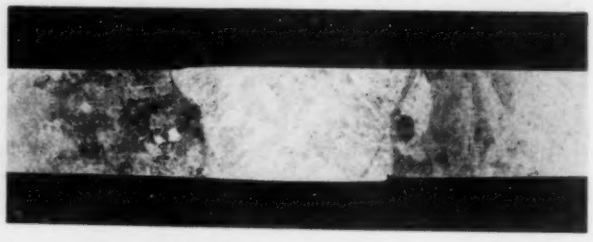
WELDED JOINT

20830 PSI. FAILED IN PARENT METAL.
21250 " " " " "
20570 " " " " "
19900 " " " " "
20637 " . AVERAGE TENSILE STRENGTH.

X-RAY: CLEAR.

ROOT BEND: 19.5° FAILED IN PARENT METAL.
FACE BEND: 24° " " " "

EFFICIENCY OF WELDED JOINT: 93.0% IN TENSILE STRENGTH.



ALUMINUM SILICON MAGNESIUM ALLOY - (356AC) - ARC WELDED

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NOT 2.
FLUX:	COVERED ELECTRODE.
ONE PASS:	3/16" ELECTRODE 28V. 360A.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.
BACKING STRIP:	GROOVED COPPER.

ORIGINAL MATERIAL (AS CAST)

TENSILE STRENGTH: 22175 PSI.
YIELD POINT: 14570 "
ELONGATION: 2.5% IN 2".
BEND: 13.5°

WELDED JOINT

19430 PSI. FAILED IN PARENT METAL
21150 " " " " "
21700 " " " " "
17200 " " " " "
20120 " AVERAGE TENSILE STRENGTH

X-RAY: CLEAR.

ROOT BEND: 15° FAILED IN PARENT METAL.
FACE BEND: 14° " " " "

EFFICIENCY OF WELDED JOINT: 90.7% IN TENSILE STRENGTH.

ALUMINUM SILICON MAGNESIUM ALLOY - (356T4) - GAS WELDED

WELDING PROCESS:	OXY-HYDROGEN.
TIP SIZE:	NO. 11.
HYDROGEN PRESSURE:	13 LBS.
OXYGEN PRESSURE:	10 LBS.
GAS MIXTURE:	NEUTRAL.
FILLER MATERIAL:	NO. 2.
FLUX:	WATER PASTE ON ROD.
NUMBER OF LAYERS:	TWO.
PLATE THICKNESS:	3/8".
TYPE OF JOINT:	OPEN, SINGLE V.

ORIGINAL MATERIAL (CAST-HEAT TREATED)

TENSILE STRENGTH: 20990 PSI.
YIELD POINT: 16425 "
ELONGATION: 2% IN 2".
BEND: 14°.

WELDED JOINT

18350 PSI. FAILED IN PARENT METAL.
19400 " " " " "
19680 " " " " "
17900 " " " " "
18832 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 11° FAILED IN PARENT METAL.
FACE BEND: 24° " " " "

EFFICIENCY OF WELDED JOINT: 89.7% IN TENSILE STRENGTH.

ALUMINUM 5% SILICON ALLOY - (43) - ARC WELDED

WELDING PROCESS: METALLIC ARC.
ELECTRODE: NO. 2.
FLUX: COVERED ELECTRODE.
ONE PASS: 1/4" ELECTRODE. 30V. 340A.
PLATE THICKNESS: 3/8".
TYPE OF JOINT: OPEN, SINGLE V.
BACKING STRIP: GROOVED COPPER.

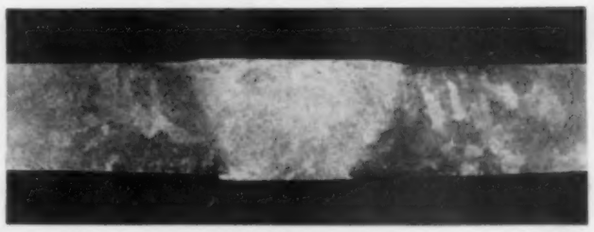
ORIGINAL MATERIAL (AS CAST)
TENSILE STRENGTH: 18950 PSI.
YIELD POINT: 10825 "
ELONGATION: 3% IN 2"
BEND: 179°.

WELDED JOINT
17160 PSI. FAILED IN PARENT METAL.
16840 " " " " "
17300 " " " " "
14570 " " " " "
16467 " AVERAGE TENSILE STRENGTH.

X-RAY: SLIGHT POROSITY.

ROOT BEND: 26° FAILED IN PARENT METAL.
FACE BEND: 20° " " "

EFFICIENCY OF WELDED JOINT: 86.8% IN TENSILE STRENGTH.



ALUMINUM COPPER ALLOY- (195AC) - GAS WELDED.

WELDING PROCESS: OXY-HYDROGEN
TIP SIZE: NO. 11.
HYDROGEN PRESSURE: 12 LBS.
OXYGEN PRESSURE: 11 LBS.
GAS MIXTURE: NEUTRAL.
FILLER MATERIAL: NO. 2.
FLUX: WATER PASTE ON ROD.
NUMBER OF LAYERS: TWO.
PLATE THICKNESS: 3/8".
TYPE OF JOINT: OPEN, SINGLE V.

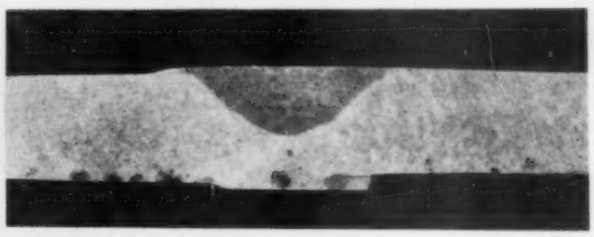
ORIGINAL MATERIAL (AS CAST)
TENSILE STRENGTH: 23925 PSI.
YIELD POINT: 18055 "
ELONGATION: 2% IN 2".
BEND: 9°

WELDED JOINT
17540 PSI. FAILED IN PARENT METAL.
17020 " " " " "
20540 " " " " "
20550 " " " " "
19912 " AVERAGE TENSILE STRENGTH.

X-RAY: SLIGHT POROSITY.

ROOT BEND: 16.5° FAILED IN PARENT METAL.
FACE BEND: 14.5° FAILED IN WELD METAL.

EFFICIENCY OF WELDED JOINT: 79.0% IN TENSILE STRENGTH.



ALUMINUM COPPER ALLOY - (195AC) - ARC WELDED

WELDING PROCESS: METALLIC ARC.
ELECTRODE: NO. 2.
FLUX: COVERED ELECTRODE.
FIRST PASS: 3/16" ELECTRODE. 33V. 390A.
SECOND PASS: 1/4" ELECTRODE. 30V. 250A.
PLATE THICKNESS: 3/8".
TYPE OF JOINT: OPEN, SINGLE V.
BACKING STRIP: SAME AS PLATE.

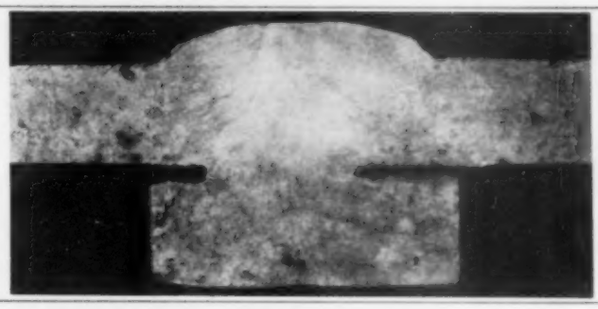
ORIGINAL MATERIAL (AS CAST)
TENSILE STRENGTH: 23925 PSI.
YIELD POINT: 18055 "
ELONGATION: 2% IN 2".
BEND: 9°

WELDED JOINT
23480 PSI. FAILED IN PARENT METAL.
22170 " " " " "
22300 " " " " "
22650 " AVERAGE TENSILE STRENGTH.

X-RAY: SLIGHT POROSITY.

ROOT BEND: 17°. FAILED IN BASE METAL.
FACE BEND: 21°. " " "

EFFICIENCY OF WELDED JOINT: 94.6% IN TENSILE STRENGTH.



ALUMINUM COPPER ALLOY - (195T4) - GAS WELDED.

WELDING PROCESS: OXY-HYDROGEN.
TIP SIZE: NO. 11.
HYDROGEN PRESSURE: 11 LBS.
OXYGEN PRESSURE: 10 LBS.
GAS MIXTURE: NEUTRAL.
FILLER MATERIAL: NO. 1, 1/4".
FLUX: WATER PASTE ON ROD.

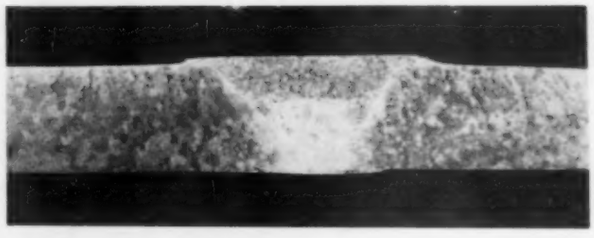
ORIGINAL MATERIAL (CAST - HEAT-TREATED)
TENSILE STRENGTH: 32900 PSI.
YIELD POINT: 25360 "
ELONGATION: 5.5% IN 2".
BEND: 21°

WELDED JOINT
22100 PSI. FAILED IN THE WELD
20000 " " " " FUSION ZONE.
16150 " " " " PARENT WELD.
23400 " " " " WELD.
20412 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 10° FAILURE IN WELD.
FACE BEND: 14° " " PARENT METAL.

X-RAY: POROUS.

EFFICIENCY OF WELDED JOINT: 62.0% IN TENSILE STRENGTH.



ALUMINUM COPPER ALLOY (195T4) - ARC WELDED.

WELDING PROCESS: METALLIC ARC.
ELECTRODE: NO. 2.
FLUX: COVERED ELECTRODE.
FIRST PASS: 3/16" ELECTRODE. 35V. 390A.
SECOND PASS: 1/4" ELECTRODE. 32V. 415A.
PLATE THICKNESS: 3/8".
TYPE OF JOINT: OPEN, SINGLE V.
BACKING STRIP: SAME AS PLATE.

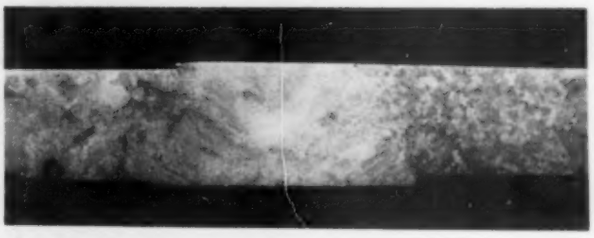
ORIGINAL MATERIAL (CAST -HEAT TREATED)
TENSILE STRENGTH: 32900 PSI.
YIELD POINT: 25360 "
ELONGATION: 5.5% IN 2".
BEND: 21°

WELDED JOINT
23960 PSI. FAILURE IN FUSION ZONE
24280 " " " "
25060 " " " PARENT METAL
27270 " " " " "
25090 " AVERAGE TENSILE STRENGTH

ROOT BEND: 17° FAILURE IN FUSION ZONE AND WELD.
FACE BEND: 19° FAILURE IN PARENT METAL.

X-RAY: SCATTERED POROSITY.

EFFICIENCY OF WELDED JOINT: 76.2% IN TENSILE STRENGTH.



ALUMINUM COPPER ALLOY - (195T4) - ARC WELDED.

WELDING PROCESS: METALLIC ARC.
ELECTRODE: NO. 2.
FLUX: COVERED ELECTRODE.
ONE PASS: 1/4" ELECTRODE. 30V. 340A.
PLATE THICKNESS: 3/8".
TYPE OF JOINT: OPEN, SINGLE V.
BACKING STRIP: GROOVED COPPER.

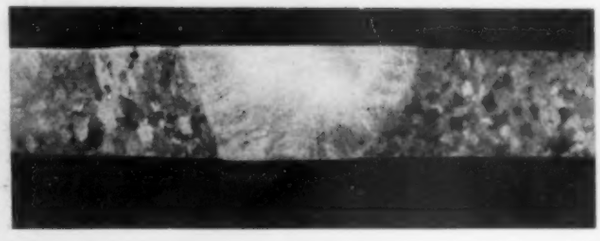
ORIGINAL MATERIAL (CAST-HEAT TREATED)
TENSILE STRENGTH: 32900 PSI.
YIELD POINT: 25360 "
ELONGATION: 5.5% IN 2".
BEND: 21°.

WELDED JOINT
28470 PSI. FAILURE IN FUSION ZONE.
26600 " " " " "
25330 " " " " WELD.
27400 " " " " "
26950 " AVERAGE TENSILE STRENGTH.

ROOT BEND: 14° FAILURE IN WELD
FACE BEND: 23° FAILURE IN WELD

X-RAY: POROUS.

EFFICIENCY OF WELDED JOINT: 81.9% IN TENSILE STRENGTH.



was of commercially pure aluminum, while that used for the arc welds was of 5% silicon alloy. This undoubtedly accounted, in part at least, for the difference in strength after welding. The best all-around properties after welding were obtained with the arc process, using a grooved copper backing strip.

Aluminum Manganese Alloy (3S)

The remarks concerning 2S material apply also to 3S. The material as received for test had tensile properties slightly higher than those expected of annealed stock. The tensile properties after welding closely approximated those of the base material in its annealed temper.

Aluminum Magnesium Chromium Alloy (52S)

The strongest joints in this material were obtained using a 5% silicon aluminum alloy electrode and the arc welding process. Better bending qualities were obtained in the oxyhydrogen welds in which pure aluminum was used as the filler metal but the strength was below that of the arc welds. The bending values for both classes of welds were much below the original material, and were of such magnitude as to indicate that welding of highly stressed parts might prove unreliable.

Aluminum Magnesium Silicon Chromium Alloy (53SO)

This is an annealed material. Each welding process produces reasonably satisfactory welds. However, some porosity was noted in all welds, and erratic values were obtained in the bend tests.

Aluminum Magnesium Silicon Chromium Alloy (53SW)

This material is the same analysis as the preceding alloy but has been heated and quenched which materially increases its tensile strength with a moderate reduction in ductility.

But one set of test plates of this material was welded. The arc welding process with a grooved copper backing strip was used, resulting in a joint of but 75% of the tensile strength of the original material and far less in bending. From welds made between this material and other aluminum alloys it seems likely that welds of slightly less tensile strength and with better bending properties would be obtained using the oxyhydrogen welding process and 5% silicon aluminum alloy filler material.

Aluminum Magnesium Silicon Chromium Alloy (53ST)

This material is also of the same chemical analysis as those preceding but has been heat treated and aged. The high tensile strength obtained by the heat treating and aging is lost when the oxyhydrogen flame is used to weld this material. The welds obtained by this process were of non-uniform strength, ranging from 8920 psi to 21,000 psi. The bending properties of the joint also were low. Both of these defects were undoubtedly due in large part to the observed porosity.

The arc-welded joint made by welding in two passes against a backing strip of the parent material showed more uniform results but also was lower in tensile strength and bending than the original material.

Aluminum 5% Silicon Alloy (43)

This material is cast and of very low ductility. When welded by the oxyhydrogen flame the resulting joint developed but 78% of the tensile strength of the original material. While the face and root and face bends of the welded joint were but 27° and 36° they were much better than the original material.

Metal arc welding using a backing strip of the parent metal and two passes gave a joint of lower tensile strength and better bending qualities than the gas weld, but using a grooved copper backing strip and welding the joint in one pass with a 1/4-inch electrode a joint of 85% of the tensile strength and of better bending qualities than the original material was obtained. In all cases, grain refinement in the welded zone would reasonably account for the observed performance.

Aluminum Silicon Magnesium Alloy (356AC)

This is a cast material of low ductility. The joints in this material made by arc welding developed better than 90% of the tensile strength of the original material with slightly better properties in bending. The gas-welded joint had about 81% of the tensile strength of the original material coupled with somewhat better properties in bending than the arc-welded joints.

Aluminum Silicon Magnesium Alloy (356T4)

This is a cast material of the same analysis as the preceding alloy but heat-treated. From the physical properties it is not evident that any improvement has been obtained by the heat treatment. The welded joints all show strengths nearly equal to the original material with better bending properties.

Aluminum Copper Alloy (195AC)

This material as cast has a tensile strength of 23,925 psi and an elongation of but 2% in 2 inches. The specimen welded by the oxyhydrogen flame developed a tensile strength of 79% of the original material with greatly improved bending properties. The arc weld made in two passes against a backing strip of the original material, developed 94% of the original material, bending an average nearly 20° as against 9° for the original material.

Aluminum Copper Alloy (195T4)

This is the same analysis as the preceding alloy but the cast material has been heat-treated resulting in an increase in tensile strength over the as-cast material and a slight improvement in ductility which is evident in the better bending properties. As in the other heat-treated alloys of aluminum the resulting welded joint made by the oxyhydrogen welding process is much lower in tensile strength than the original material being but 62% as strong. The arc-welded joint was but little stronger, 76%. Both joints falling below the original material in bending.

Aluminum Magnesium Alloy (214)

This is a cast alloy of relatively low-tensile strength and ductility. The gas-welded joint developed 83% and the arc-welded joint 100% of the tensile strength of the original material. Neither of the welded joints equaled the original material in bending.

SUMMARY

A review of the data here presented leads to the conclusion that aluminum and its commercially available alloys are weldable, but that care must be used in the application of welding and in the selection of the welding process if the best results are to be obtained.

Welding of the complex, high-strength wrought alloys in the heavy sections tested did not produce joints relatively as satisfactory as obtained with the moderate-strength binary alloys such as 3S.

In all of the alloys tested, arc welding gave better results than gas welding. In some cases this was undoubtedly due in part to the choice of electrode material, but even where the electrodes and the filler rod for gas welding were of the same composition, the ad-

ALUMINUM SILICON MAGNESIUM ALLOY - (35674) - ARC WELDED.

WELDING PROCESS:	METALLIC ARC.
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
FIRST PASS:	3/16" ELECTRODE. 36V. 375A.
SECOND PASS:	1/4" ELECTRODE. 33V. 405A.
PLATE THICKNESS:	3/8".
BACKING STRIP:	SAME AS PLATE.

ORIGINAL MATERIAL
(CAST - HEAT TREATED)

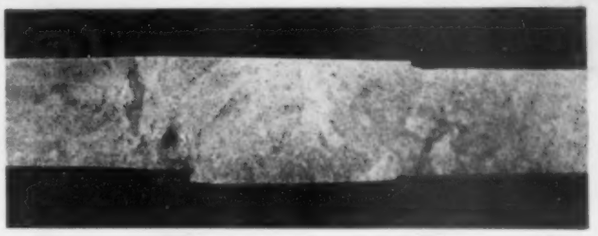
TENSILE STRENGTH:	20990 PSI.
YIELD POINT:	16495 "
ELONGATION:	2½ IN 2".
BEND:	14°.

WELDED JOINT

21200 PSI.	FAILURE IN PARENT METAL
21800 "	" " " "
19000 "	" " " "
19170 "	" " " "
20290 "	AVERAGE TENSILE STRENGTH.

ROOT BEND: 27° FAILURE IN PARENT METAL.
FACE BEND: 35° " " " "

EFFICIENCY OF WELDED JOINT: 97.1% IN TENSILE STRENGTH.



ALUMINUM SILICON MAGNESIUM ALLOY - (35674) - ARC WELDED

WELDING PROCESS:	METALLIC ARC
ELECTRODE:	NO. 2.
FLUX:	COVERED ELECTRODE.
ONE PASS:	1/4" ELECTRODE. 30V. 340A.
PLATE THICKNESS:	3/8".
BACKING STRIP:	GROOVED COPPER.

ORIGINAL MATERIAL
(CAST - HEAT TREATED)

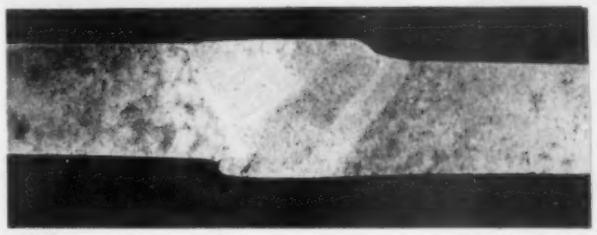
TENSILE STRENGTH:	20990 PSI.
YIELD POINT:	16495 "
ELONGATION:	2½ IN 2".
BEND:	14°

WELDED JOINT

21040 PSI.	FAILED IN PARENT METAL
20060 "	" " FUSION ZONE.
21120 "	" " PARENT METAL
21400 "	" " " "
20905 "	AVERAGE TENSILE STRENGTH.

ROOT BEND: 180° FAILED IN FUSION ZONE
FACE BEND: 180° FAILED IN PARENT METAL.

EFFICIENCY OF WELDED JOINT: 99.6% IN TENSILE STRENGTH.



vantage in favor of arc welding persisted. It is felt that the better heating and cooling cycle obtained with arc welding was largely, if not entirely, responsible for the advantages noted.

The alloys in which welding showed to best advantage were the cast, coarse-grained alloys. In these, the welding induced local grain-refinement, contributing to improved properties.

It cannot be too strongly emphasized that the present investigation dealt only with a single relatively heavy section, and that attempts to extend the comments based on results with this section to other sections, particularly those substantially lighter, may lead to erroneous conclusions. The only comment of general applicability which it is safe to make is that welding of sections strengthened either by cold work or by heat treatment will tend to reduce the strength at and near the welds to values approaching the strength of fully annealed materials. Such effects must always be kept in mind when the welding of aluminum alloys is under consideration.

The conclusions expressed in the foregoing paper are the personal opinions of the authors, and in no way express the opinion of the Navy Department.

ACKNOWLEDGMENTS

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Discussion of Dr. C. G. Suits' paper on "Welding Arcs from the Standpoint of Recent Investigations"*

By W. G. DOW†

I HAVE read Dr. Suits' paper carefully and with great interest. It seems to me to be an excellent assembly of those results of recent fundamental research that are pertinent to properties of welding arcs.

Dr. Suits occupies at the present time a unique position in the electrical industry. I do not believe that it is an exaggeration to state that no man anywhere is as well informed as he is in regard to the properties of electric arcs when operating at pressures at and above atmospheric. And considering the complexity of the subject that is no mean distinction. He has of course contributed important discoveries of his own in this field, but in my estimation his most important and outstanding contributions have grown out of his thorough analytical criticism and evaluation of a great variety of conflicting theories and experimental results relative to arcs. As a result of this analytical work he can authoritatively state in readable form, as he has done in the present paper, the essential facts and theories relative to almost any aspect of the behavior of arcs at atmospheric and higher pressures. Dr. Langmuir and his coworkers brought order out of chaotic thinking in regard to low-pressure arcs some 10 or 12 years ago; Dr. Suits has now done so in regard to the high-pressure range, and he deserves much credit for the success of his efforts.

I believe the relation between Dr. Suits' presence here and the work of engineering educators in the field of electronics should be mentioned. Obviously, useful interpretation of the fundamental theory of electric arcs lies

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† Associate Professor of Electrical Engineering, University of Michigan.

primarily in the field of work of electrical engineers, rather than of mechanical or metallurgical engineers. This is only one illustration of the increasing importance of electrical engineers' contributions to the welding art. But even electrical engineers trained in the curricula of ten years ago, find much of Dr. Suits' paper difficult reading.

One of the significant recent developments in engineering education has been the introduction into engineering curricula of courses which give to engineering students an appreciation of the basic concepts of all branches of electronic study. The response of electrons in gases to voltage gradients; ionization and excitation of atoms and molecules; the signifiance of potential distributions; the mechanism of light production by arcs; atomic spectra as employed in spectrographic metallurgical analysis; the meaning of the term "thermal ionization;" heat transfer by conduction and convection; . . . the interpretation and use of these and many other new electrical concepts are part of a modern electrical engineering curriculum.

For example, Dr. Suits has given a very interesting equation, as follows:

$$\log_{10}\left(\frac{n^2}{N}\right) = -\frac{5040\ Ve}{T} + 1.51 \log_{10} T + 15.38$$

In interpreting this relation to our students I would rewrite it in the exponential form, as follows:

$$\frac{n^2}{N} = 2.4 \times 10^{15}\ T^{3/2}\ \epsilon^{-\frac{Ve}{VT}}$$

where V_T is the voltage equivalent of the arc temperature. Such a form of this relation is harder to work with numerically than that given by Dr. Suits, but is much easier to interpret physically.

Along with the job of giving oncoming engineers some knowledge of electronic theory and its applications we have that of offering to earlier engineering graduates, who did not have such work in college, opportunities in the form of extension work for acquiring it now. We must also try to cooperate with and extend the research activities carried out by industrial organizations.

One always asks, in regard to a paper such as that now under discussion, to what tangible, useful results will it lead? I believe that we all hope that out of continued fundamental research work on arcs there may ultimately grow a method of welding in which the human element is somewhat less critically important than it is today. Perfection in electric arc welding will not be reached until the bead laid down by the welder is consistently as smooth and homogeneous as a piece of molding. We may none of us live to see such welds, but progress toward the ideal should be possible. It is only by becoming able to understand, interpret, and extend ideas such as those presented by Dr. Suits that we can hope to make substantial advances toward this ideal.

By PAUL L. BETZ*

Under the heading "Anode, Cathode and Positive Column" Dr. Suits discusses minimum arc voltage. Experiments are cited in which an arc was drawn between electrodes that were made to approach each other. The cathode ray oscillograph was used to observe the arc voltage, and it is reported that a discontinuity in the voltage was found to exist for electrode separations of less than one-ten thousandth centimeters. Other work on minimum arc voltage has been reported in the literature, but has been overlooked in the bibliography of the present paper. Attention is directed to a paper by Betz and Karrer, *Journal of Applied Physics*, December 1937, page 845, entitled "A Characteristic of the Copper Arc During the Formative Period." In this paper the cathode ray oscillograph was used to observe the voltage that arises across a pair of electrodes as an arc is initiated by the separation of a pair of electrodes initially in contact and carrying current. The observations were at atmospheric pressure and indicate that the arc voltage rises in less than one ten-thousandth seconds to a value that is independent of the current and voltage of the circuit. This initial voltage is the minimum voltage that exists across the electrode. For copper, the minimum arc voltage is approximately 12.2 volts. It is suggested in this paper that the positive column drop and the anode fall contribute nothing to the minimum voltage drop inasmuch as these functions of the arc are non-existent at the time the minimum arc voltage exists. It is further suggested that the minimum arc voltage corresponds to the cathode potential drop of the arc inasmuch as its value is independent of the value of the arc current.

* Consolidated Gas, Electric Light and Power Co. of Baltimore, Md.

By CARL KENTY*

The outstanding contributions of Dr. Suits to the study of arc phenomena, including the velocity of sound method for measuring the temperature and the general method of treating arcs as problems in heat transfer, are too well known to require further discussion.

As Dr. Suits has shown, the most important advance in our knowledge of the arc in recent years, starting from the work of Compton in 1923, has been the recognition that a state of thermodynamic equilibrium, at a temperature of the general order of 6000° K., exists in the core of the arc among the electron ions, and neutral and excited atoms. The existence of such an equilibrium in the positive column of the arc aids tremendously in the calculation of the conductive and radiative properties of the column. It is suggested that further studies would be desirable of the mechanisms of metal transfer in the welding arc, and of the heat dissipation to the individual electrodes.

As pointed out by Dr. Suits, if a method could be found for determining the distribution of potential along the arc it would enable direct knowledge to be gained of the individual cathode and anode drops, quantities which are of fundamental importance in the welding arc.

* G. E. Vapor Lamp Co.